IPSO SUBSTITUTION IN SELECTED PHENOLIC SYSTEMS

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ABSTRACT

Reaction of 2-chloro- (28a), 2-bromo- (28b) and 2-methyl (28c) 6-nitro-4-methylphenols with fuming nitric acid at 50° gives the 5-chloro (29a), 5-bromo- (29b) and 5-methyl- (29c) 2-methyl-3-nitro-1,4-benzoquinones respectively, each reaction involving methyl migration to the ring carbon adjacent to the nitro substituent. Reaction of 2,6-dibromo- (50) and 2,3,6-tribromo- (31) 4-methylphenols with fuming nitric acid at 50° gives the 2,6-dibromo- (51) and 2,3,5-tribromo- (48) 1,4-benzoquinones respectively, each reaction involving methyl loss. A reaction mechanism is proposed for these transformations.

Reaction of tetrabromo- (55) and tribromo-6-nitro- (58) 4-methylphenols with fuming nitric acid at 50° gives the corresponding 4-nitrato-4-methylcyclohexa-2,5-dienones (56) and (59) *via* the 4-hydroxy-4-methylcyclohexa-2,5-dienones (57) and (60). Similar reactions are observed for 4-ethyl substrates.

Treatment of tetrabromo- (63) and tribromo-6-nitro (66) 4-hydroxy-4-ethylcyclohexa-2,5-dienones with concentrated sulphuric acid gives the 3,5,6-tribromo- (71) and 5,6-dibromo-3-nitro- (67) 2-ethyl-1,4-benzoquinones. When the ethyl groups were replaced by methyl groups, reaction proceeds to give diphenylethane products (73) and (75).

Treatment of tetrabromo- (57), tetrachloro- (77), 2,3,5-tribromo-6-methyl- (81) and 3,5-dibromo-2,6-dimethyl- (84) 4-hydroxy-4-methylcyclohexa-2,5-dienones with sodium hydroxide yields C3-hydroxy derivatives; the 2,5,6-tribromo-

3,4-dihydroxy-4-methylcyclohexa-2,5-dienone (80) was identified by X-ray crystal analysis. Treatment of 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60) with sodium hydroxide gives 3,4-dibromo-5-methyl-5-(2'-nitroethan-1'-one)-2(5H)-furanone (86), identified by X-ray crystal analysis. A mechanism is proposed for this reaction.

Rearrangement of tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in (D)-chloroform gives tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77) and 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89). The rearrangement is further investigated using several solvents and variously substituted 4-methyl-4-nitrodienones, sometimes in the presence of a radical scavanging phenol. A mechanism is postulated for the rearrangement.

CHAPTER I

GENERAL INTRODUCTION

The nitration of aromatic compounds has been the subject of much research over an extensive period of time. As a result of this work it has been found that nitration reactions can be carried out in a variety of reaction media, the most common reagent being nitric acid used either neat, in water, in mineral acids, in inert organic solvent or in acetic anhydride. Nitrations can also be performed using the nitrogen oxides, N_2O_4 and N_2O_5 and with nitrogen containing salts, e.g. $[NO_2^+BF_4^-]$, in various solvents.

NITRATING AGENT

As early as 1903, Euler[1] suggested that the actual nitrating agent may be the nitronium ion, NO_2^+. Since then considerable evidence has been accumulated to support this theory for many of the above media.

Nitration in Concentrated Nitric Acid. In concentrated nitric acid, molecular nitric acid, HNO_3, has been found to be the main species present, however physical and spectroscopic measurements demonstrate the existence of significant concentrations of other species.

By studying the variation of the freezing point of mixtures of dinitrogen pentoxide, N_2O_5, and water over a range of concentrations encompassing the formation of pure nitric acid, it was shown[2,3] that appreciable self-

dehydration was occurring according to the following scheme:

$$2HNO_3 \rightleftharpoons NO_2^+ + NO_3^- + H_2O \quad .$$

At the freezing point of nitric acid (-42°), the concentrations of water, nitronium ion, and nitrate ion were found to be of the order of 0.4 to 0.7 mol ℓ^{-1}. Similar values were found for the concentration of the three species at -10° and -20° by electrical conductivity measurements.[4]

The infrared spectrum of nitric acid confirms the presence of the nitronium ion[5] and its Raman spectrum[6] confirms the presence of both nitrate and nitronium ions in concentrations of 0.37 and 0.34 mol ℓ^{-1} respectively.

Nitration of aromatics in concentrated nitric acid have generally been found to react according to the following rate law:

$$\text{Rate} = k_1[\text{ArH}] \quad .$$

As nitric acid is the reaction solvent, terms involving its concentration cannot enter the rate equation, but this form of the rate equation is consistent with reaction *via* molecular nitric acid, or any species whose concentration throughout the reaction bears a constant ratio to the stoichiometric concentration of nitric acid. In the latter case, the nitrating agent may account for any fraction of the total concentration of acid, provided that it is formed quickly relative to the rate of nitration.

Sulphuric acid catalyses nitration in concentrated nitric acid. The acceleration in the rate is not linear

in the concentration of the catalyst, for the sensitivity to catalysis is smaller with lower concentrations of sulphuric acid, but eventually approaches a linear acceleration with higher concentrations of sulphuric acid.

Potassium nitrate anticatalyses nitration in nitric acid but again, as in the case of the addition of sulphuric acid, the effect is not linear in the concentration of the additive.

The approach of the kinetic form of the catalysis to the linear law only when the concentration of the additive was greater than c. 0.2 mol ℓ^{-1}, results from the equilibria existing in anhydrous nitric acid. In the absence of catalyst, nitric acid undergoes appreciable self-dehydration to yield nitronium ions, nitrate ions and water. The addition of sulphuric acid allows the operation of another mode of ionization:

$$HNO_3 + H_2SO_4 \rightleftharpoons NO_2^+ + HSO_4^- + H_2O$$

The nitronium ions produced in this way tend to suppress the self-dehydration of the nitric acid and therefore the nett concentration of nitronium ions is not proportional to the concentration of the catalyst until sufficient sulphuric acid has been added to make the self-ionization of nitric acid relatively unimportant.

The effect of potassium nitrate on the rate arises in a similar way. The concentration of nitrate ions in concentrated nitric acid is appreciable and only when the concentration of added nitrate exceeds that of the nitrate present in pure nitric acid will anticatalysis become proportional to the concentration of added salt. The

observations above strongly suggest that under these conditions the nitronium ion is indeed the nitrating agent.

Nitration in Aqueous Nitric Acid. In the presence of a large concentration of water it has been postulated that the nitronium ion would be unlikely to exist and that nitration may involve the nitric-acidium ion, $H_2NO_3^+$.[7] Indeed the intensity of the peak in the Raman spectrum associated with the nitronium ion does decrease with the progressive addition of water, and the peak is absent from the spectra of solutions containing more than about 5% water.[6a] A similar effect has been observed in the infra-red spectrum.[5] However strong evidence now exists for the nitronium ion as the reagent responsible for nitration under these conditions.

Nitration at a rate independent of the concentration of the compound being nitrated would be observed if the bulk reactivity of the aromatic towards the nitrating species exceeded that of water, and the measured rate would then be the rate of production of the nitrating species. The identification of the slow reaction with the formation of the nitronium ion followed from the fact that the initial rate under zeroth-order conditions was the same to within experimental error, as the rate of ^{18}O-exchange between nitric acid and water in a similar solution in the absence of aromatic.[8] In a given solution, if exchange involves the nitronium ion, the concentration of which is constant, then the rate of exchange is either the rate of formation of nitronium ion or the rate of its destruction, these being equal. Thus, it was inferred that the exchange of oxygen occurred *via* heterolysis to the nitronium ion,

and that it was the rate of this heterolysis which limited the rates of nitration of reactive aromatic compounds. If the effective reagent were the nitric-acidium ion, there would be no necessary connection between the rates of the two processes.

In aqueous nitric acid containing as much as c. 60 mol% of water the nitronium ion is still the effective nitrating agent.

Nitration in Inert Organic Solvents. The absence of ions in mixtures of acetic acid and nitric acid is shown by their poor electrical conductivity[9] and the Raman spectra of nitric acid in acetic acid, nitromethane and chloroform show only the absorptions of the solvent and molecular nitric acid. Although the nitronium ion cannot be detected by physical methods in these media, kinetic studies have provided compelling evidence for the formation and effectiveness of this species in nitration.

From observations of zeroth-order nitration in organic solvents it appeared that the effective nitrating agent was formed from nitric acid in a slow step. Since proton transfers are unlikely to be slow, the nitrating agent is probably formed by heterolysis, and is most likely to be the nitronium ion. Detailed support for this conclusion comes from the effects of added species on the rate.[10]

Nitration in organic solvents is strongly catalysed by small concentrations of strong acids; typically a concentration of 10^{-3} mol ℓ^{-1} of sulphuric acid doubles the rate of reaction.[11] Potassium nitrate strongly anticatalyses nitration; the anticatalysis is linearly

related to the concentration of added nitrate.[11] These effects are typical of those expected for nitration *via* the nitronium ion, as discussed earlier.

In the case of nitration in carbon tetrachloride, when very low concentrations of nitric acid are used, the zeroth-order rate of nitration depends on the concentration of nitric acid approximately to the fifth power.[12] It is argued therefore that five molecules of nitric acid are associated with a pre-equilibrium step or are present in the transition state. Since nitric acid is evidently not extensively associated in carbon tetrachloride a scheme for nitronium ion formation might be as follows:

$$5HNO_3 \rightleftharpoons \begin{matrix} NO_2^+ \\ \vdots \\ NO_3^-.HNO_3 \end{matrix} + \begin{matrix} H_3O^+ \\ \vdots \\ NO_3^-.HNO_3 \end{matrix}$$

The concentration of molecular aggregates might be expected to increase with a fall in temperature as is indeed observed through studying the rate of the reaction at these low concentrations of nitric acid.[12]

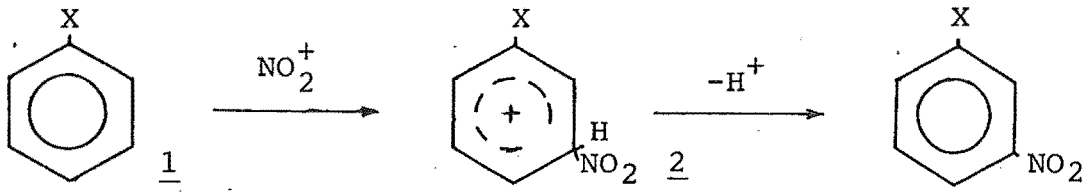
Nitration with Nitric Acid in Acetic Anhydride. Nitric acid and acetic anhydride react together to give acetyl nitrate rapidly and almost quantitatively. Among organic solvents acetic anhydride is particularly potent in nitrations and reaction in it occurs under relatively mild conditions.

The nature of the electrophile operating in reagents prepared from acetic anhydride has been much argued; acetyl nitrate, protonated acetyl nitrate, dinitrogen pentoxide and nitronium ion have been advocated. Although conclusive

evidence is not yet available to settle this uncertainty, it appears most likely that the nitrating agent is either the protonated acetyl nitrate, $AcONO_2H^+$, or the nitronium ion formed within an encounter complex containing the aromatic and the precursor of the nitronium ion, possibly $AcONO_2H^+$.

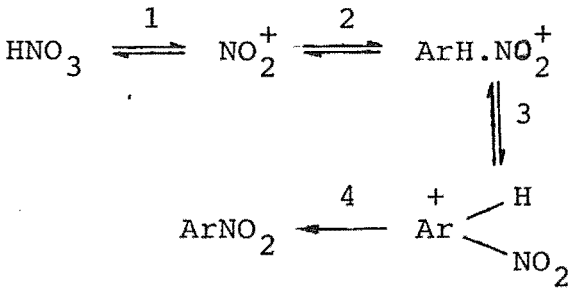
NITRATION MECHANISM

For electrophilic nitronium ion reaction with a monosubstituted benzene derivative (1), attack may occur at two types of ring carbons. For the first type, reaction at the unsubstituted *ortho*, *meta* and *para* ring positions (conventional attack), the characteristics of the reaction are well understood and the process normally results in overall substitution.



1 2

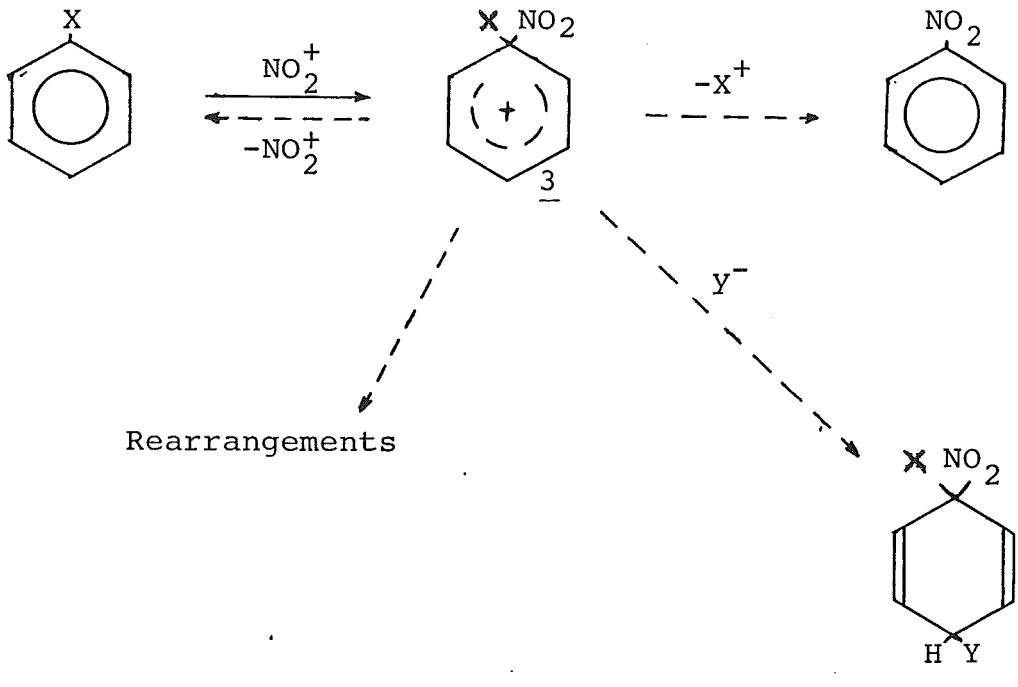
The complete nitration procedure is considered to involve four possible rate determining steps (1→4):



Step (1) has sometimes been observed to be rate-determining, notably when nitrating a reactive aromatic compound with nitric acid in an inert organic solvent. Here the

nitronium ion is not readily formed due to the non-polar solvent conditions. In step (2) the nitronium ion and the aromatic compound diffuse together to give an encounter pair of undefined structure which then produces a Wheland intermediate (2), step (3). Loss of a proton (step (4)) from the Wheland intermediate to generate the nitro compound is generally fast and only rate determining in special structural situations.

In the second type of reaction nitronium ion attack occurs at the substituted position to give the Wheland intermediate (3). A prefix '*ipso*' was introduced by Perrin and Skinner[13] to describe this type of attack:



addition products.

For Wheland intermediates (3), benzenoid stability cannot be regained by simple proton loss. As a result four basic reaction paths may be followed to give more stable products. The first two pathways are simple and involve the loss,

either of NO_2^+ to reform the starting material, or of X^+ leading to an overall substitution. The third type of reaction involves the capture of the Wheland intermediate (3) by nucleophilic attack at a site remote from the *ipso* position or by loss of a proton from a hydroxyl group to generate a dienone system. These processes may produce a stable molecule, or only exist as a step in an ongoing rearrangement. The fourth type of reaction involves direct rearrangement of the Wheland intermediate (3); often by 1,2- or 1,3-migrations of groups to neighbouring ring positions.

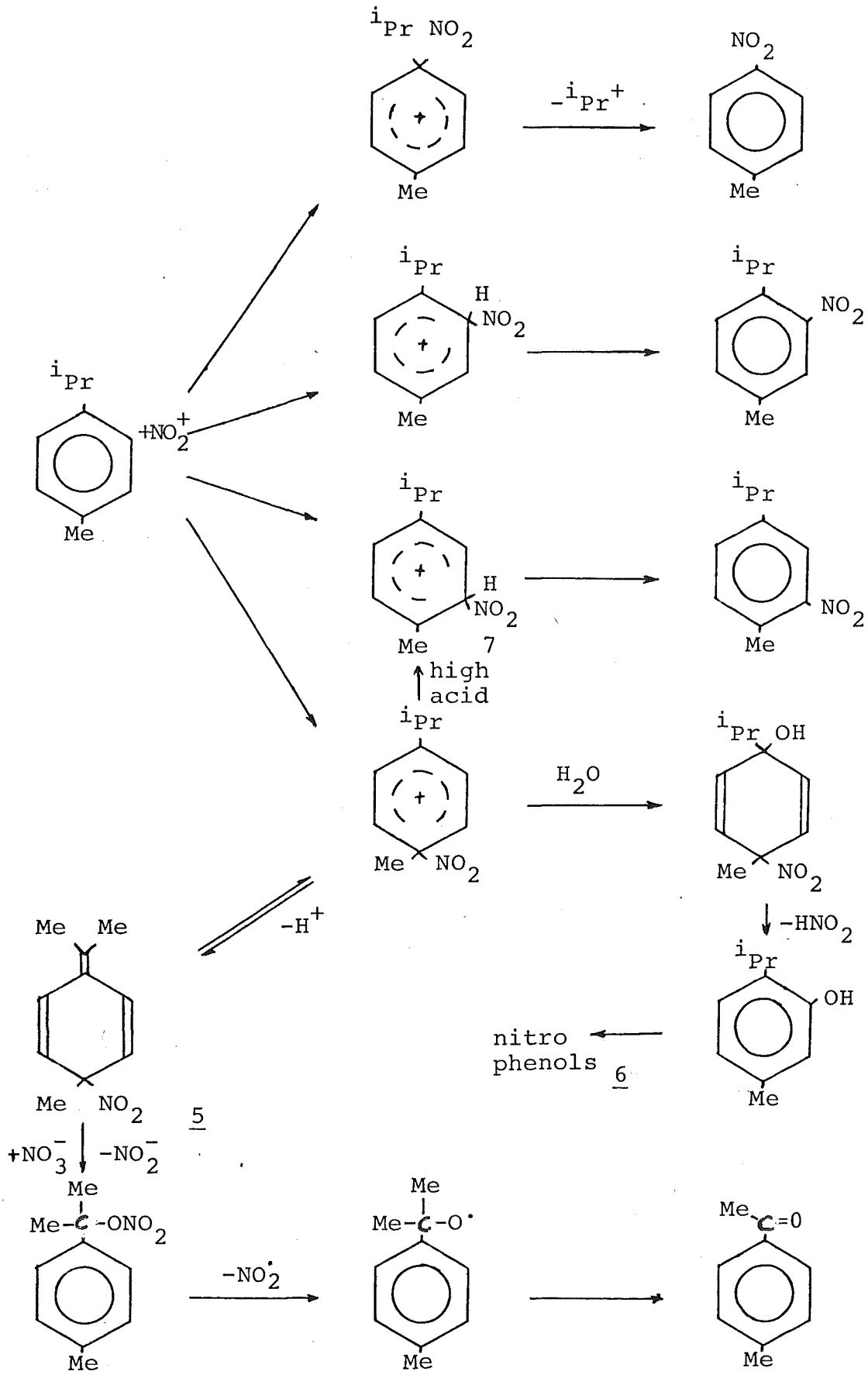
Ipso Substitution and Functional Group Transformations.

Many *ipso* substitutions occur in aromatic compounds which are strongly activated towards electrophilic attack. Nitro-de-alkylation and nitro-de-halogenation are among the most common forms of *ipso* substitution.

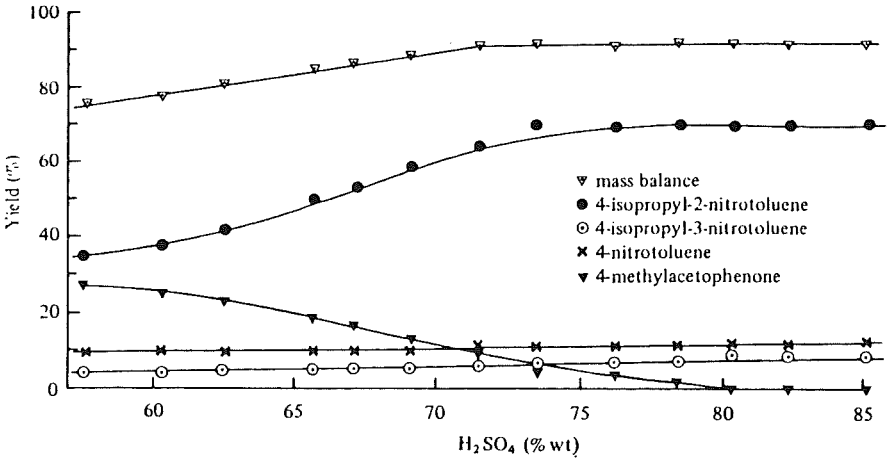
Nitro-de-alkylation. In nitro-de-alkylation the more stable tertiary alkyl leaving groups are more easily displaced than primary and secondary alkyl groups. In fact, it is not certain that straightforward displacement of a primary alkyl group by *ipso*-nitration has been observed as apparent cases of this kind of reaction may proceed by initial modification of the alkyl group.

Kinetic studies[14] show that in aqueous sulphuric acid p-cymene is nitrated at a rate similar to that of toluene. Formation of the observed products are believed to occur *via* the mechanism shown in Scheme 1.

The variations in yields of these products with acidity are shown in Figure 1.


i-Pr NO2
-i-Pr+
NO2
Me
i-Pr
+NO2+
H
NO2
7
high acid
H2O
i-Pr OH
-HNO2
OH
nitro phenols 6
-H+
Me Me
Me NO2 5
+NO3-
-NO2-
Me-C-ONO2
-NO2·
Me-C-O·
Me-C=O

Scheme 1



Nitration of *p*-cymene. Open triangles, aggregate yield; filled circles, 4-isopropyl-2-nitrotoluene; filled triangles, 4-methylacetophenone; crosses, 4-nitrotoluene; open circles, 4-isopropyl-3-nitrotoluene.

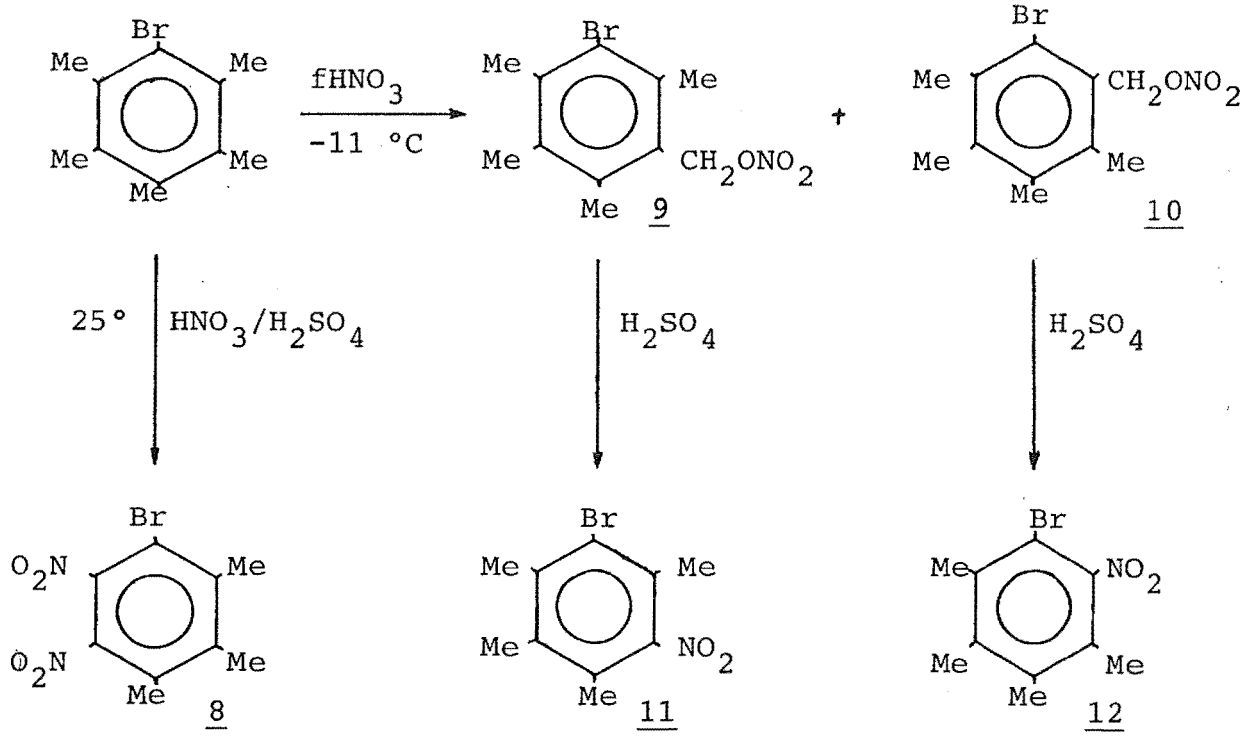
Figure 1

Some doubt did exist as to the mechanism for the formation of the 4-nitrotoluene. Although a simple nitro-de-isopropylation substitution mechanism seemed likely for the formation of this product, the possibility that the product was produced *via* the 4-methylacetophenone did exist. However, the nitration of 4-methylacetophenone has been carried out with no observed de-isopropylated products.[15]

The formation of the p-methylacetophenone appears to require an equilibrium step involving the loss of a proton to give the structure (5). It would be expected that this step would be less favoured under high acidity conditions. As the methyl group is unlikely to be lost directly, 1,2-migration of the nitro group to give the Wheland intermediate (7), followed by deprotonation occurs to give increased yields of the 4-isopropyl-2-nitrotoluene.

In 1940, Smith and Horner[16] obtained a mixture of nitrates (9) and (10) from the treatment of bromo-penta-

methylbenzene with fuming nitric acid, but with fuming nitric acid and sulphuric acid the product isolated was 1-bromo-2,3,4-trimethyl-5,6-dinitrobenzene(8), Scheme 2. Further treatment of the nitrates (9) and (10) with sulphuric acid gave the demethylated products (11) and (12).

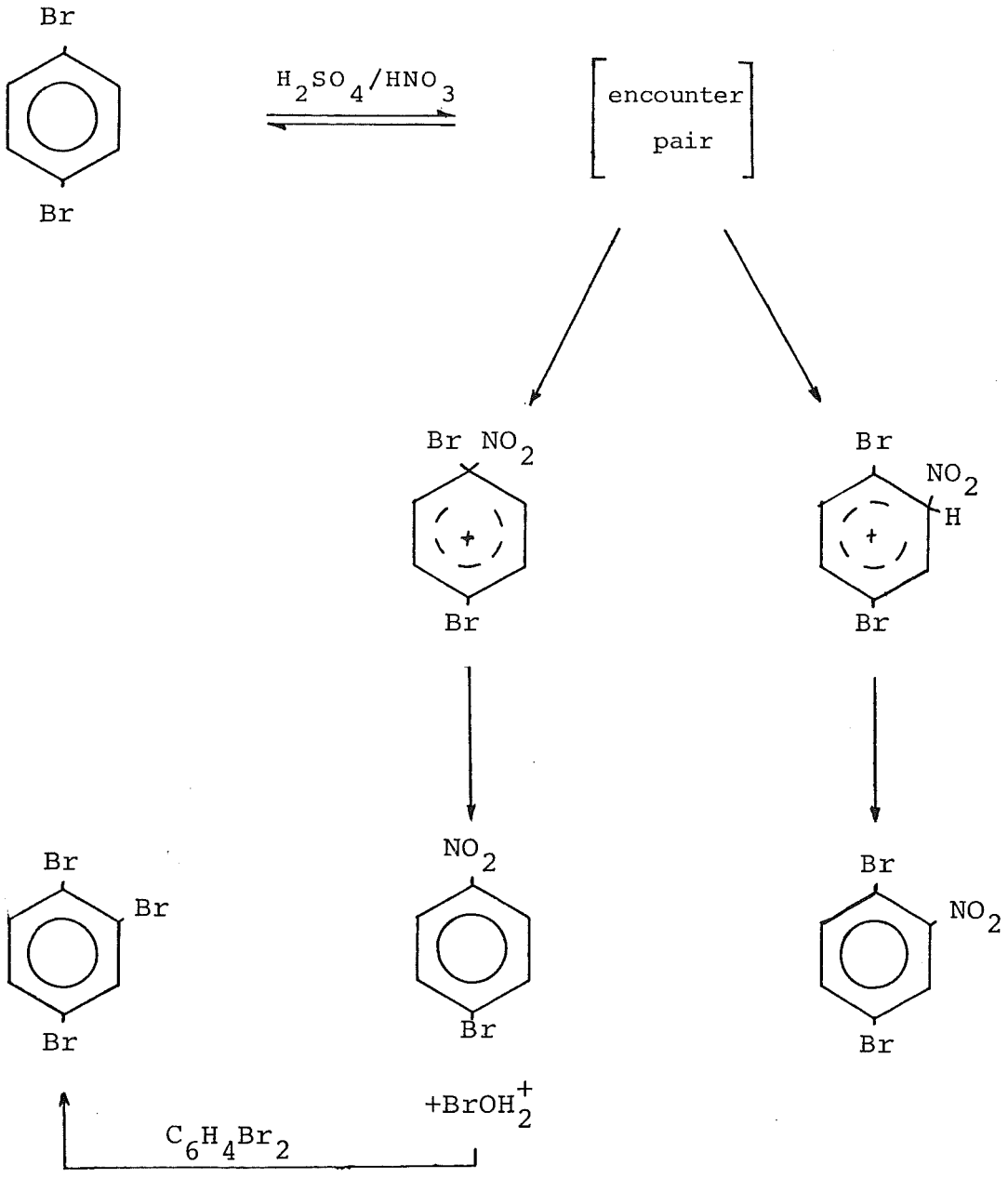


Scheme 2

On the basis of these observations Smith and Horner suggested that the organic nitrate group ($-CH_2ONO_2$) may be an intermediate in nitrations involving the replacement of a methyl group by a nitro group.

Nitro-de-halogenation. Nitro-de-halogenation experiments suggest that the leaving ability of the *ipso* substituent is in the order $Cl<NO_2<Br<I$. Nitro-de-brominations have been reported but nitro-de-chlorinations

have been observed only rarely. For example in the reaction of 1,4-dibromobenzene with sulphuric and nitric acids three products were observed.[17] The results were interpreted as shown in Scheme 3.



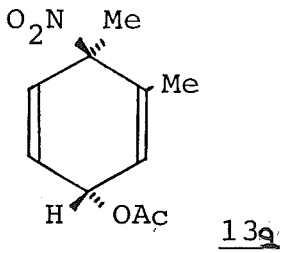
Scheme 3

The yield of 1-bromo-4-nitrobenzene decreased with increasing acidity suggesting that water plays a part in the removal of the positively charged bromine ion.

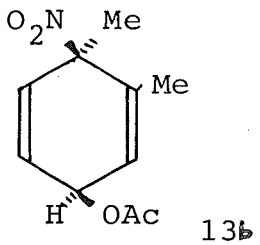
Nucleophilic Capture of the *Ipso*-Wheland Intermediate.

Attack on the *ipso*-Wheland intermediate (3) by a nucleophile at a site remote from the *ipso*-position has been postulated as a step in the formation of a number of nitration products. One example is that of compounds (6) in the nitration of p-cymene, above.

Evidence for this 'capture' mechanism comes from the acetoxylation of *o*-xylene with nitric acid in acetic anhydride. In the past 4-acetoxy-*o*-xylene has been observed as the major product from the above reaction, but Blackstock *et al.*[18] were able to isolate two intermediate products from the reaction mixture, which were identified as (13a) and (13b) below:

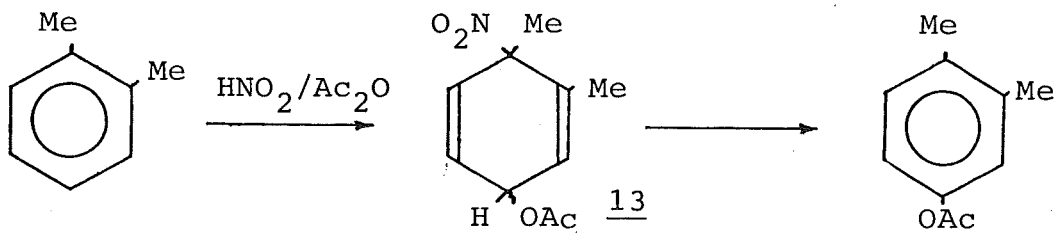


13a



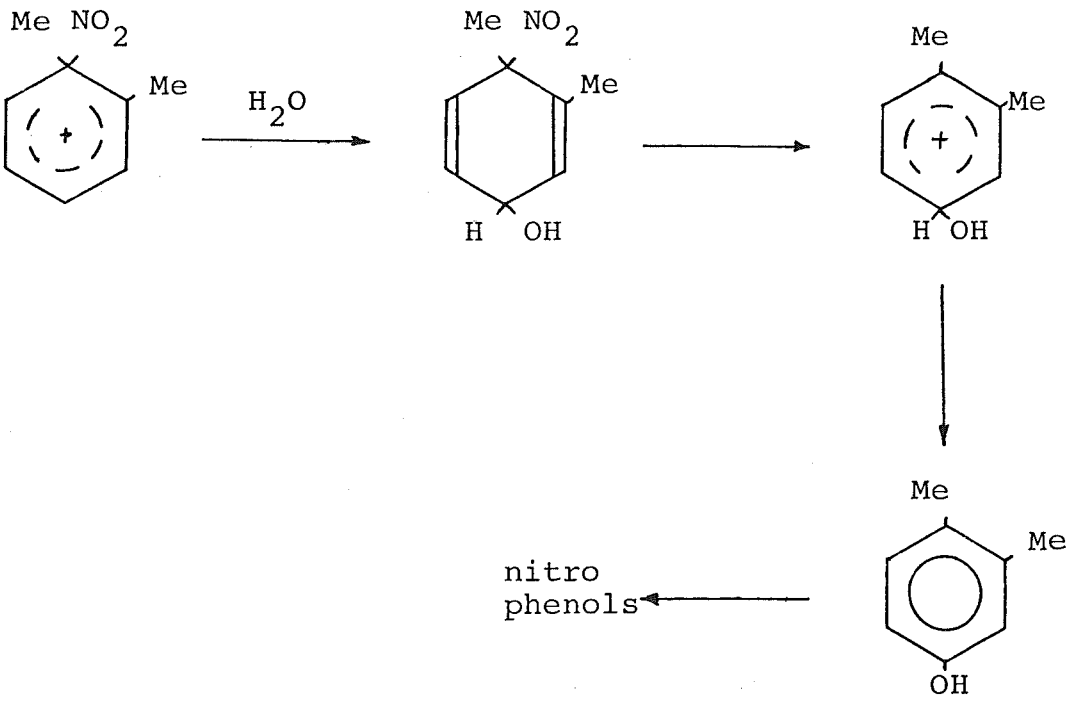
13b

These products (13) have been observed to rearrange, with elimination of nitrous acid, in aqueous acid media and on gas-liquid chromatography to give 4-acetoxy-*o*-xylene, Scheme 4.



Scheme 4

With nitrations carried out in aqueous acids nucleophilic attack by water has been observed, often resulting in the formation of phenols which are readily nitrated further under the conditions of reaction. In 60% sulphuric acid, *o*-xylene gives 33% of mono- and di-nitro-3,4-dimethylphenol[19], the mechanism proposed for this mechanism is shown in Scheme 5.



Scheme 5

MIGRATION

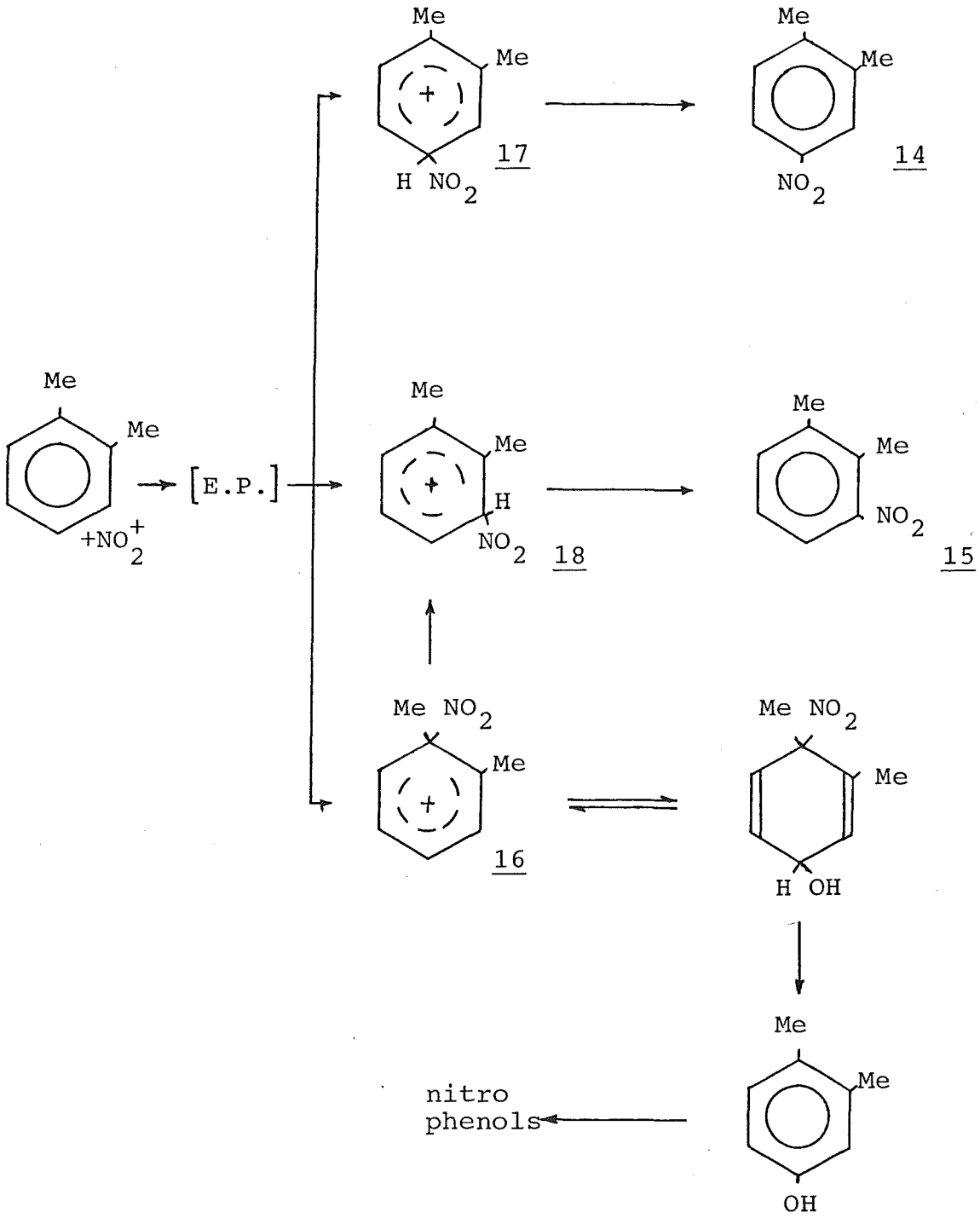
Under more acidic conditions less water is available for nucleophilic addition to the *ipso* Wheland intermediate and migrations are more commonly observed. The Wheland intermediate formed by *ipso*-nitration appears to be capable of rearranging in two ways; by migration of nitro, or by migration of X. As the migratory aptitude

of the nitro group is quite considerable, the second of the possibilities above is rarely observed.

Nitro-Migration. Migrations of the nitro group may be separated into three catagories; intra-, extra- and inter-molecular. By intramolecular migration is meant a process in which the nitro group never becomes sufficiently free from the carbon structure to do other than move to a position adjacent to the *ipso*-position, i.e.: 1,2-migration occurs. In extramolecular migration the nitro group becomes free enough to be able to distinguish and select amongst the positions in the carbon structure, but it does not leave the encounter pair containing it and the carbon structure. In intermolecular rearrangements the *ipso*-nitro group leaves its position, diffuses into the solvent, and may react with carbon structures other than that which it left.

Myhre first discerned the occurrence of intramolecular 1,2-migration in offering an explanation[19] of the acidity dependence of the ratio of 3- to 4-nitro-*o*-xylene produced in the nitration of *o*-xylene in sulphuric acid.[20] He suggested that the *ipso* Wheland intermediate formed by nitronium ion attack *ipso* to the methyl group is captured by water at low acidities (page 14), but that with increasing acidity, 1,2-migration becomes increasingly important, Scheme 6. Although the nitrobenzene products (14) and (15) prepared from the nitration of *o*-xylene could be formed through direct nitration as shown in Scheme 6, it was conceivable that (15) could also be formed *via* the *ipso* Wheland intermediate (16) by a 1,2-migration followed by proton loss. Indeed the increased ratio of 3- to

4-nitro-*o*-xylene produced with increasing acidity, i.e.: increased 1,2-migration, supported the importance of this second mechanism.



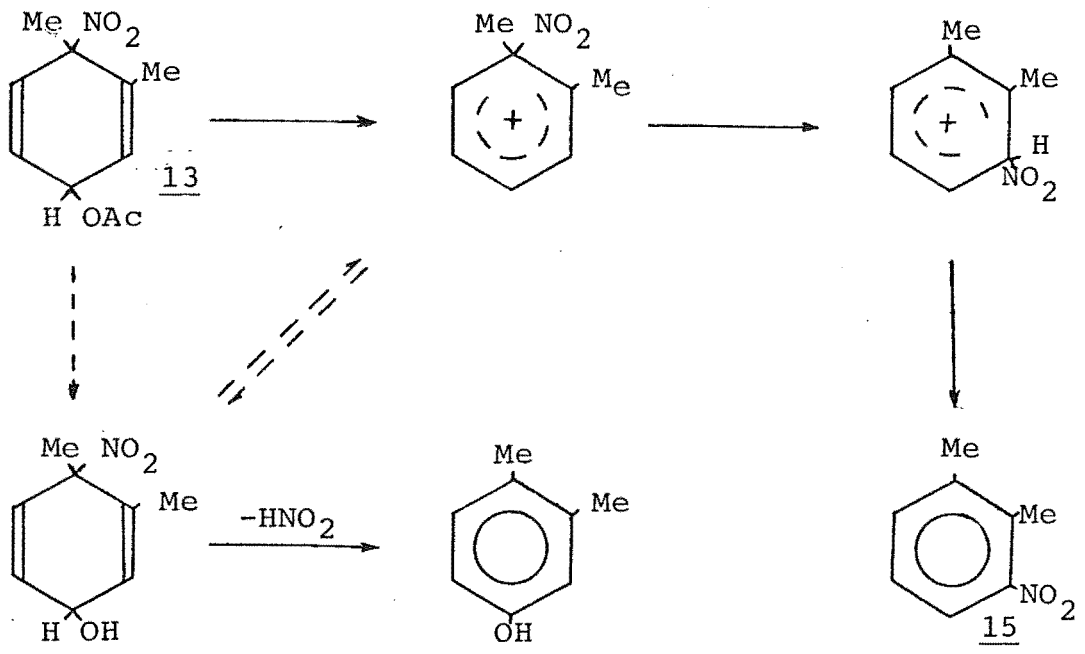
Scheme 6

An ideal test for this intramolecular rearrangement would involve preparation of the ion (16) by a route unlikely to yield either (17) or (18) as first-formed intermediates. Myhre accomplished this by solvolysing the higher melting form of the nitro-acetate (13) in sulphuric acid of several concentrations.[19] Solvolysis of (13) in aqueous systems is known to yield 4-acetoxy-*o*-xylene, but at higher acidities alkyl-oxygen cleavage to form the ion (16) could be anticipated. Indeed at increasing acidities the solvolysis of the higher melting form of the nitro-acetate (13) gave the 3-nitro-*o*-xylene (15) in increasing yield with no 4-nitro-*o*-xylene(14) being observed, Table 1 and Scheme 7.

Solvolysis of the Higher Melting Compound (13)

% H_2SO_4	49.3	59.9	70.2	85.1%
3-nitro (15)	2%	15%	80%	93%
4-nitro (14)	-	-	-	-

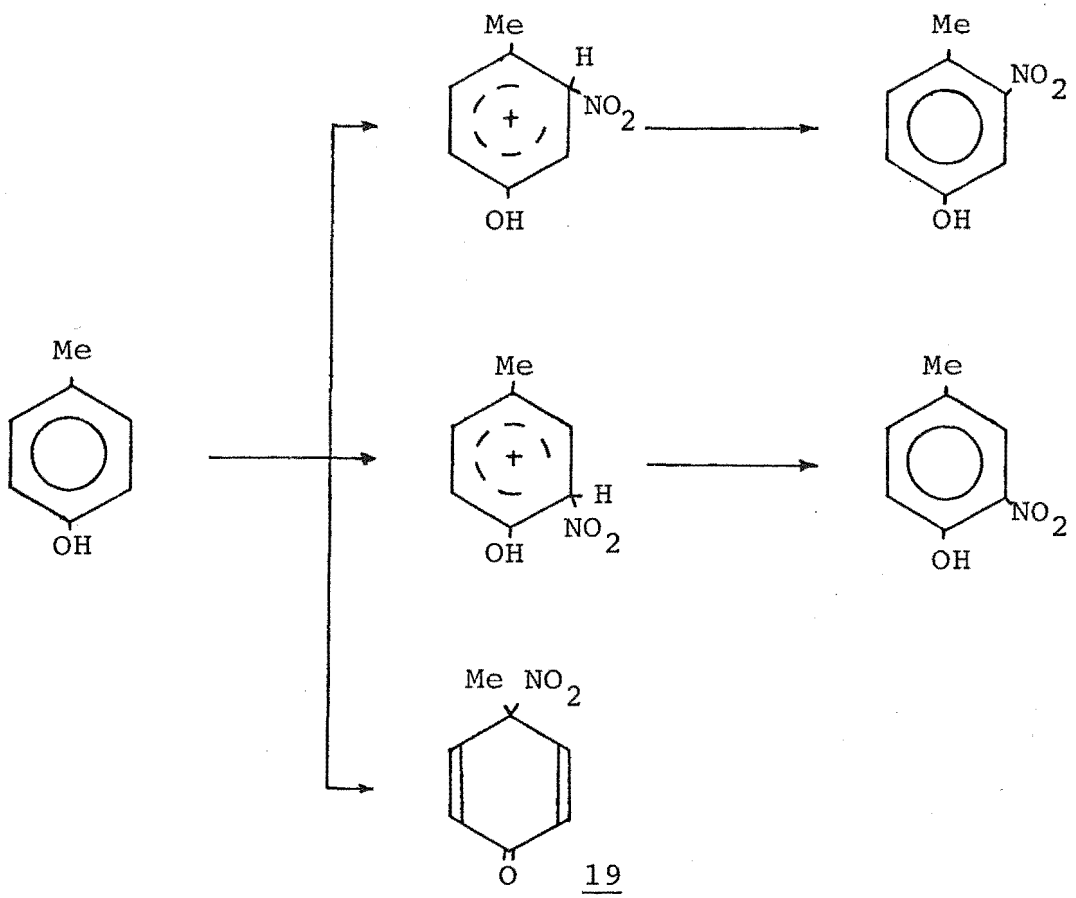
Table 1



Scheme 7

Since the solvolysis of (13) gave no 4-nitro-*o*-xylene (14), return of the Wheland intermediate (16) to encounter pairs does not compete in this case with migration or capture.

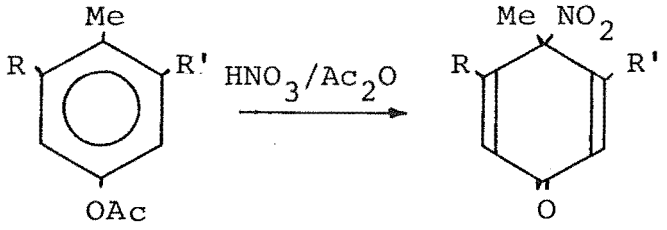
Extramolecular nitro group migration has been observed mainly in nitration of phenols and anisoles. Nitration of 4-methylphenol could be expected to occur at the *ortho*- and *meta*- positions to give simple nitration and also by *ipso*-attack at the methyl substituted position to give the 4-methyl-4-nitrocyclohexa-2,5-dienone(19), Scheme 8.



19

Scheme 8

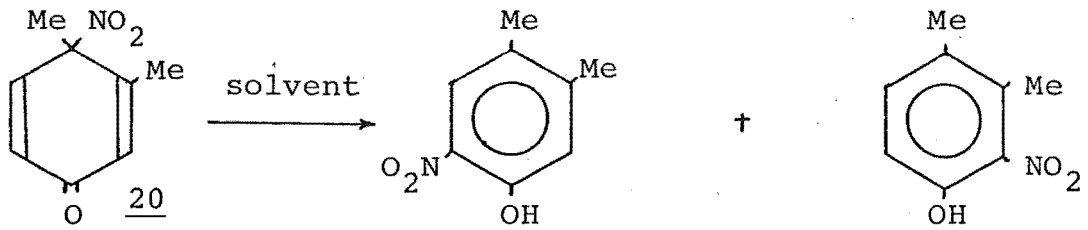
Although aromatization of 4-nitrocyclohexa-2,5-dienones by 1,3-shift of the nitro group had been documented earlier[21], the results reported by Myhre *et al.*[22] gave more detailed information about the rearrangement mechanism. Nitration of three substituted 4-methyl-phenyl acetates with nitric acid in acetic anhydride at 0° gave the corresponding 4-methyl-4-nitrocyclohexa-2,5-dienones(19), (20) and (21) in good yields[22], Scheme 9. These 4-methyl-4-nitrodienones (19), (20) and (21) rearomatized in a variety



19 R=H, R'=H
20 R=H, R'=Me
21 R=Me, R'=Me

Scheme 9

of solvents (hexane, acetic acid, ethanol, water) to yield products of a formal 1,3-shift of the nitro-group, Scheme 10. Reaction characteristics observed by Myhre *et al.*



Scheme 10

in these rearrangements were:

(1) the rates of formation of the nitrophenols equaled rates of reactant disappearance,

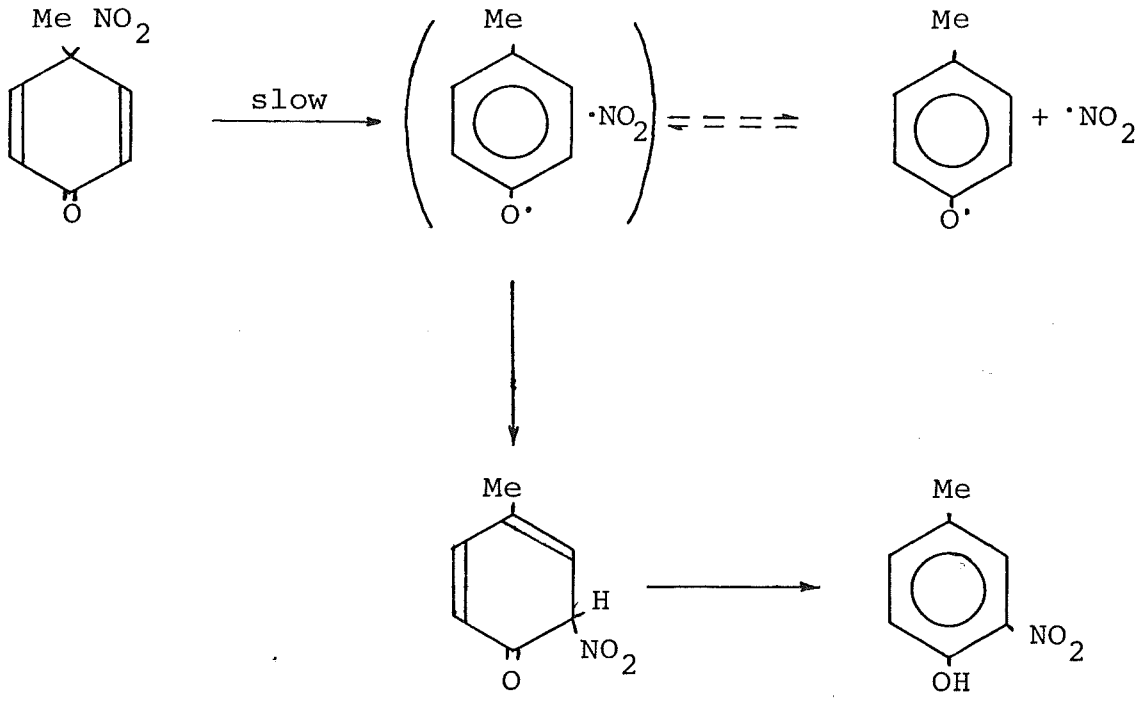
(2) the reaction rates decreased as the polarity or hydrogen bonding ability of the solvent increased,

(3) the activation entropies were small but positive,

(4) the addition of radical scavangers did not alter reaction rates but did reduce the yield of nitrophenol products and increased yields of alkylphenol products,

(5) the reactivity order 19>20>21 was observed.

Myhre suggested a radical-dissociation-recombination mechanism as shown in Scheme 11 for this rearrangement where dissociation is rate-determining. Polar solvents

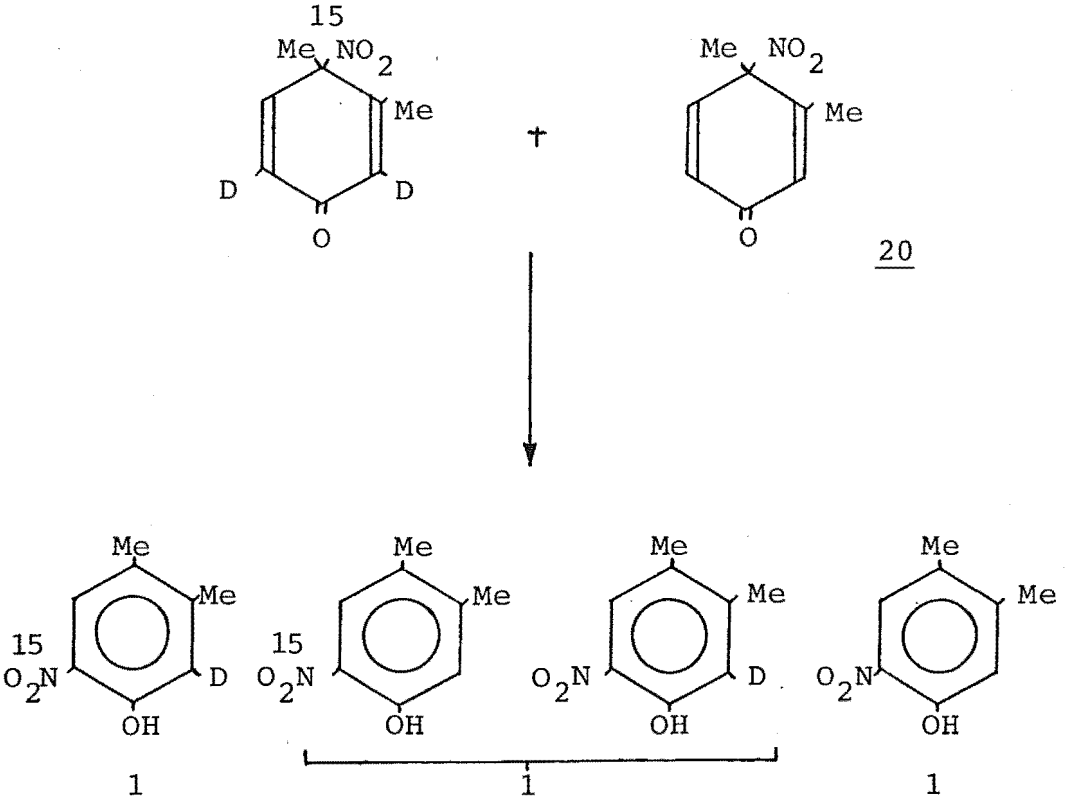


Scheme 11

presumably stabilize the reagents and reduce rearrangement rates. It was suggested that steric effects that increase on going from reactant to phenoxy radical may account for

the reactivity order 19>20>21.

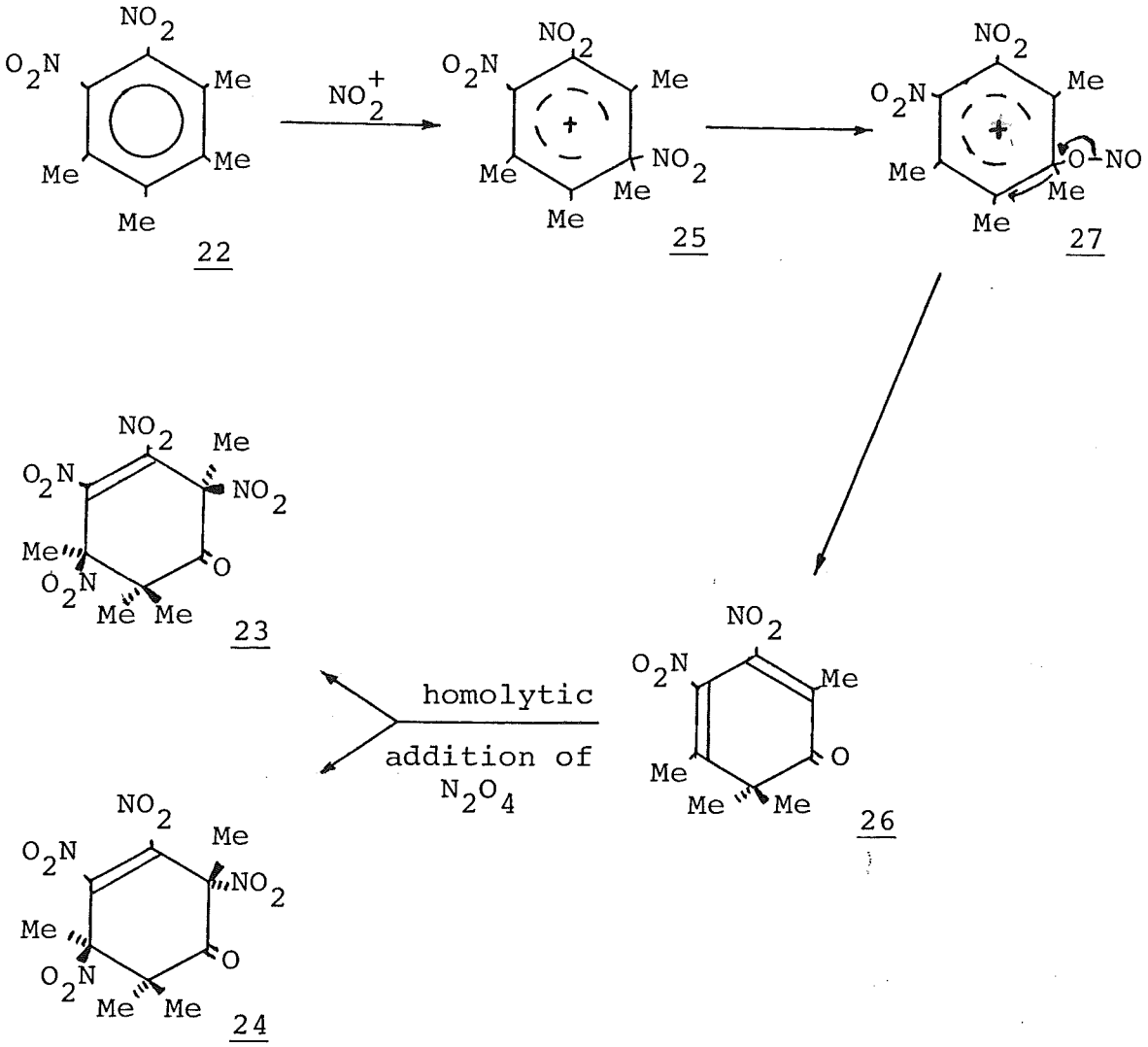
From isotopic labelling studies[22] in which compound (20) was rearranged in *n*-hexane with an equal amount of the [^{15}N]-2,6-d_2 form of compound (20) it was found that approximately 50% scrambling was occurring, Scheme 12. This scrambling is from loss of the NO_2 radical from the solvent cage resulting in intermolecular rearrangement.



Scheme 12

Methyl-Migration. Although uncommon, methyl-migration has been observed in the nitration of the 1,2,3,4-tetramethyl-5,6-dinitrobenzene (22) in fuming nitric acid to give the *cis*- and *trans*-2,5,6,6-tetramethyl-2,3,4,5-tetranitrocyclohex -3-enones(23) and (24)[23]. A likely reaction mechanism for the formation of these two products is *via* nitronium ion attack at the ring position

most activated to electrophilic attack to give the *ipso*-Wheland intermediate (25), which gives rise to the dinitro dienone (26), probably though the nitrito derivative (27). Subsequent homolytic two-step 1,4-addition of dinitrogen tetroxide to the dinitro dienone (26) then yields the observed products (23) and (24), Scheme 13. Crystal-structure identification of product (23) is discussed in Appendix 1.



Scheme 13

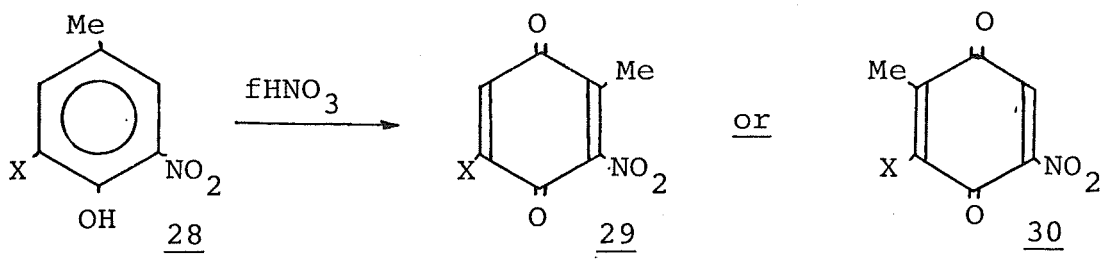
CHAPTER II

NITRATIONS OF 2,6-DISUBSTITUTED AND 2,3,6-TRISUBSTITUTED 4-METHYLPHENOLS

INTRODUCTION

In 1903, Zincke *et al.*[24,25] reported that the nitration of 2-chloro-4-methyl-6-nitrophenol(28a) with fuming nitric acid gave a compound which was either the 5-chloro-2-methyl-3-nitro-1, 4-benzoquinone(29a) or the 3-chloro-2-methyl-5-nitro-1, 4-benzoquinone(30a). Although Zincke was able to assign a molecular formula to this product from elemental analysis data, and indicated its general structure, the precise structure of the compound could not be determined using the techniques available at that time.

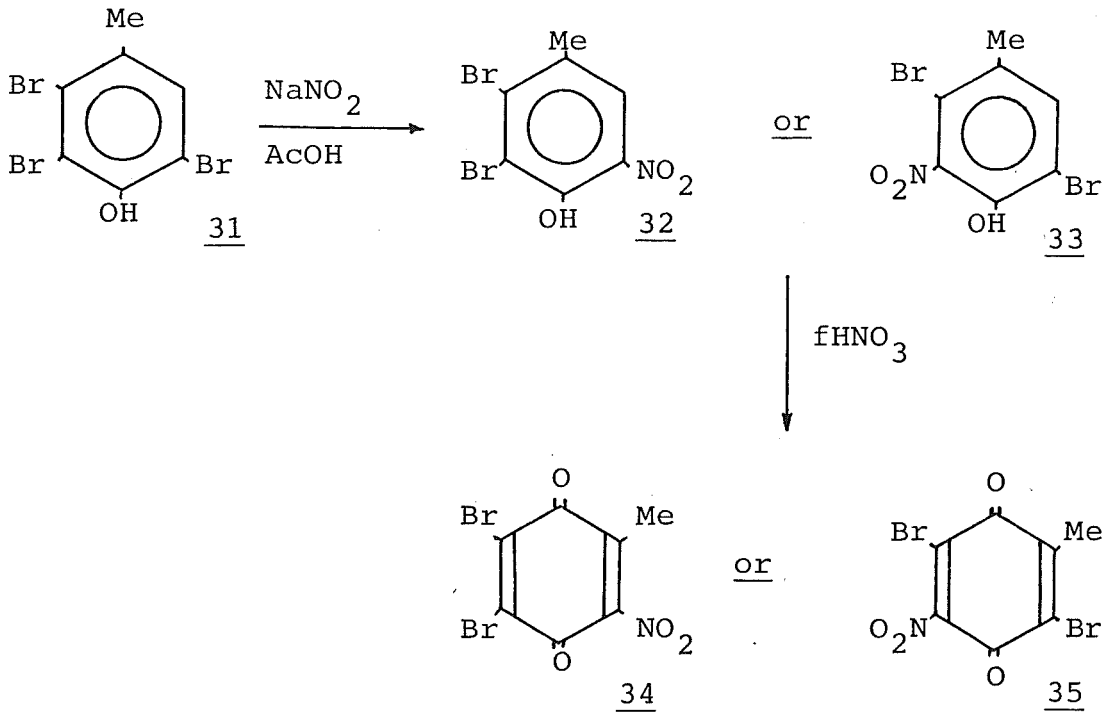
Similar uncertainty existed concerning the identity of the nitration product from 2-bromo-4-methyl-6-nitrophenol (28b) when reacted under the same conditions as above. Zincke *et al.*[24,26] reported the product as either the 5-bromo-2-methyl-3-nitro-1,4-benzoquinone(29b) or the 3-bromo-2-methyl-5-nitro-1,4-benzoquinone(30b).



28 29 30

a = Cl
b = Br
c = CH_3

In addition, reaction of 2,3,6-tribromo-4-methylphenol(31) with sodium nitrite in acetic acid was reported to yield a dibromonitrophenol (32) or (33)[26], which on nitration, as for the phenols (28a) and (28b) above, gave the 2,3-dibromo-5-methyl-6-nitro-1,4-benzoquinone(34) or the 2,5-dibromo-3-methyl-6-nitro-1,4-benzoquinone(35)[24,26]. Again the information available could not distinguish between the two possible isomeric structures postulated as products for each of the reactions, Scheme 14.



Scheme 14

DISCUSSION

Repetition of the nitration of 2-chloro-4-methyl-6-nitrophenol(28a) using fuming nitric acid at 50° gave the 5-chloro-2-methyl-3-nitro-1,4-benzoquinone(29a)(52%), the

structural assignment of which is discussed below. The remaining material isolated consisted of a complex mixture of polar oils.

Similarly, repetition of the nitration of 2-bromo-4-methyl-6-nitrophenol(28b) as for the compound (28a) above, gave the 5-bromo-2-methyl-3-nitro-1,4-benzoquinone(29b)(63%) with the remaining material again consisting of polar oils.

We are now able to resolve the uncertainty that has existed regarding the true structure of the substituted 1,4-benzoquinones(29a) and (29b) by a comparison of their ^{1}H n.m.r. spectra, Table 2. As the chemical shifts of

^{1}H n.m.r. Chemical Shifts (p.p.m.) for the 1,4-Benzoquinones(29a) and (29b)

	methyl	C6-proton
29a	2.13	7.17
29b	2.13	7.43

Table 2

protons in the ^{1}H n.m.r. spectra reflects their chemical environments, then the similarity in chemical shifts of the methyl-protons in the compounds (29a) and (29b) (both δ2.13), suggests that the methyl groups are in similar structural and electronic environments. This would be consistent with the proposed structures of (29a) and (29b). Note that the alternative structures (30a) and (30b), have a different halogen atom adjacent to the methyl group. This difference in environment would be expected to be reflected in the chemical shifts

of the methyl-protons.

The ring protons chemical shifts for compounds (29a) and (29b) are δ7.17 and δ7.43 respectively. This large difference in value is consistent with the change in an adjacent halogen atom as would be experienced with structures (29a) and (29b). Only a small change in the protons chemical shifts might be expected for structures (30a) and (30b) as the effect of the halogen atom is not as marked when it is more remote. This is illustrated in the example given below. 2-chloro-(37) and 2-bromo-(38) 6-methyl-1,4-benzoquinone have ^{1}H n.m.r. chemical shifts[27] as shown in Figure 2.

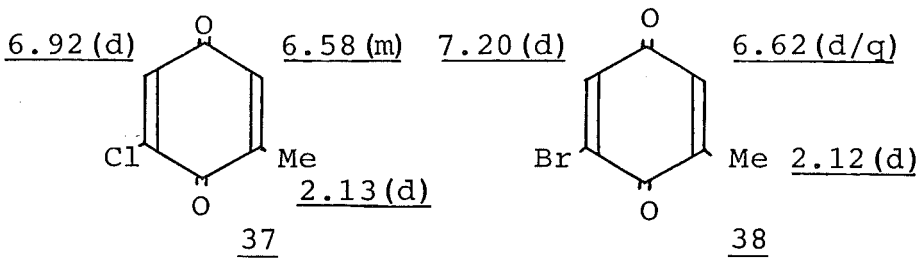
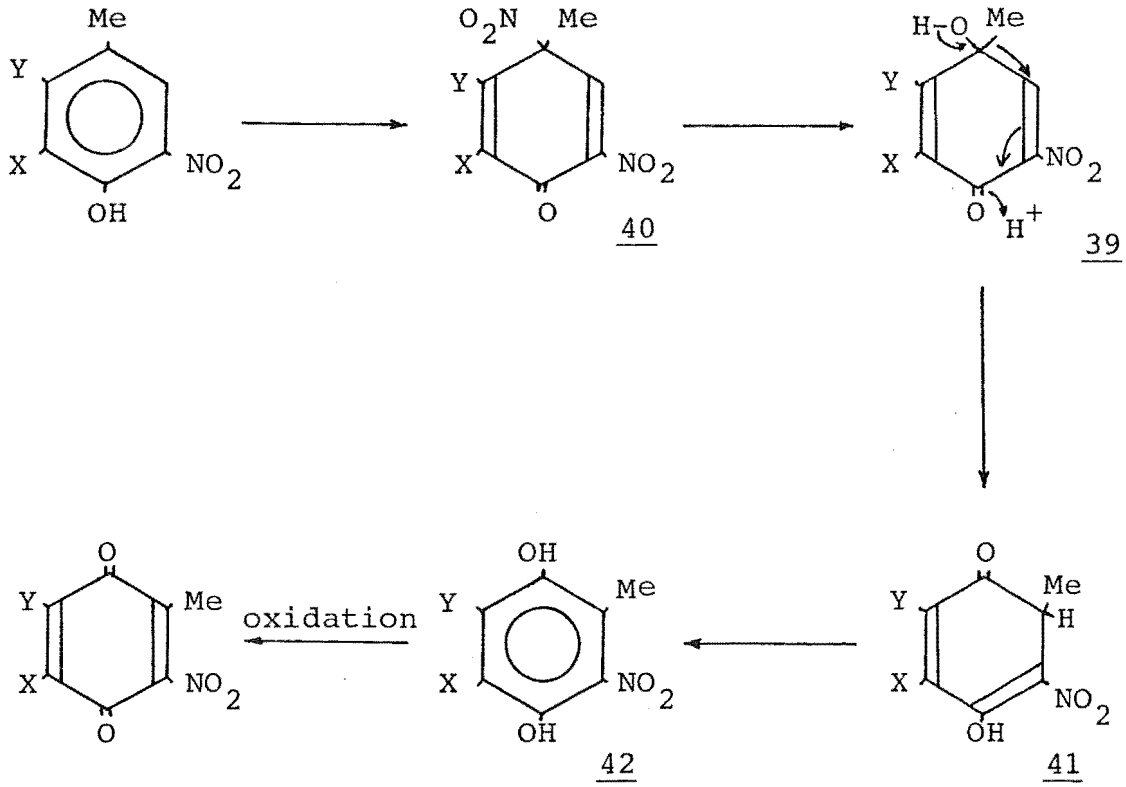


Figure 2

Note that the chemical shift of the proton adjacent to the halogen atom varies by δ0.28 when the chlorine atom is replaced by a bromine atom, whereas the proton across the ring from the halogen atom varies only by δ0.04.

It appears likely that the 2-methyl-3-nitro-1,4-benzoquinones (29a) and (29b) above, arise by acid-catalysed rearrangement of the 4-hydroxydienones (39), formed *in situ via* the 4-nitrodienone (40), Scheme 15. In the product-determining rearrangement step, the strongly electron-withdrawing nitro group would be expected to promote selective methyl-migration as shown; oxidation of either

(41) or (42) would then give the observed 1,4-benzoquinone products (29a) and (29b).



Scheme 15

Repetition of the nitro-debromination of 2,3,6-tribromo-4-methylphenol (31) using sodium nitrite in acetic acid as reported earlier[25], gave the 2,3-dibromo-4-methyl-6-nitrophenol (32). This structure is now assigned on the basis of the chemical shift of the C5-proton, δ8.00. From a comparison of the ^{1}H n.m.r. spectra of several similar phenols it was found that only an aromatic proton adjacent to a nitro group has such a downfield chemical shift, Figure 3.

Furthermore a comparison of the observed ^{13}C n.m.r. spectrum and those calculated for the alternative structures

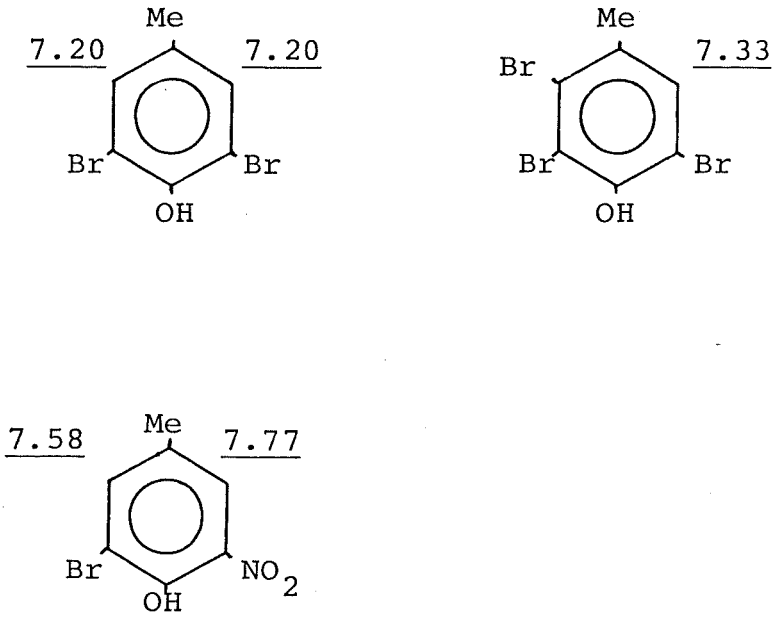


Figure 3

(32) and (33)[28] supported the above arrangement, Table 3. Note that the resonance assigned to the unsubstituted

Calculated ^{13}C n.m.r. Chemical Shifts[28]

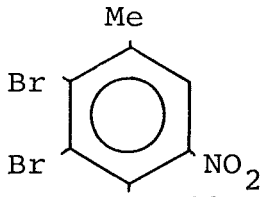
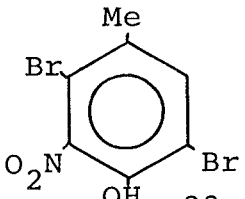
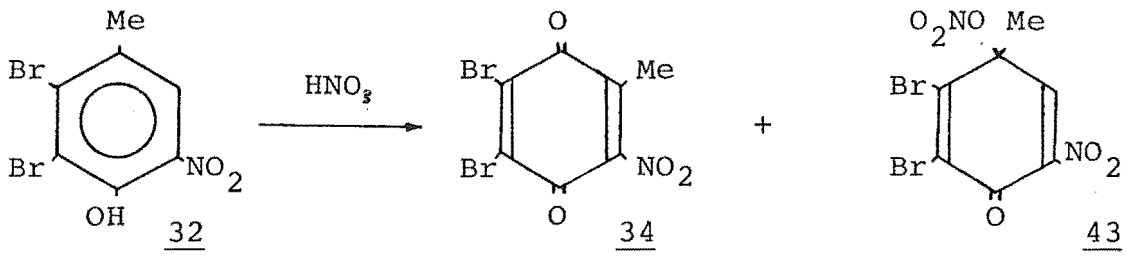
	 32	 33	Observed
1	152.8	152.8	149.3
2	114.6	140.9	115.6
3	134.4	118.8	130.1
4	135.6	136.5	135.9
5	126.9	141.6	123.0
6	135.9	109.6	-

Table 3

carbon, which would be expected to have a small T_1 value, was clearly visible at δ123.0 in the observed ^{13}C n.m.r. spectrum because of its strong signal. The only calculated spectra with such an up-field unsubstituted carbon is the structure (32).

Nitration of the 2,3-dibromo-4-methyl-6-nitrophenol (32) as for the phenols (28a) and (28b) above, gave the 2,3-dibromo-5-methyl-6-nitro-1,4-benzoquinone(34) (38%) and the 2,3-dibromo-4-methyl-4-nitrato-6-nitrocyclohexa-2,5-dienone(43) (11%), Scheme 16. Although uncertainty had



Scheme 16

existed as to the correct structure of the 1,4-benzoquinone, it can now be assigned the structure (34) on the basis of a sound knowledge of the structure of its precursor (32) and an understanding of the reaction mechanism, Scheme 15. Analytical data was in agreement with the proposed structure (34).

The nitratodienone (43) could be expected to be similar, electronically, to substituted 4-hydroxy-4-methyl-cyclohexa-2,5-dienone and indeed the chemical shifts of all protons in its ^1H n.m.r. spectra were very close to those observed in the hydroxydienones discussed later. From the infra-red spectrum the organic nitrate group was clearly visible with bands at 1661, 1279 and 831 cm^{-1} and the conjugated ketone structure and the nitro group

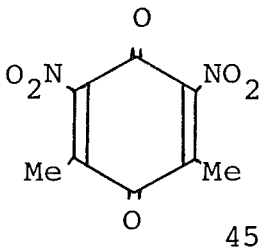
were indicated by the bands at 1701 and 1546 cm^{-1} respectively. Analytical data was in accord with the proposed structure.

The nitratodienone (43) produced in the nitration of the phenol (32) is probably formed from the hydroxy-dienone (39) by esterification with nitric acid in competition with the acid-catalysed rearrangement.

In the light of the above results it was decided to investigate the effect of substituting the halogen atom for a methyl group in these nitrations. Nitration of the 2,4-dimethyl-6-nitrophenol(28c), as for the phenols (28a) and (28b) above, gave only a low recovery of identifiable products. The product isolated in higher yield (17%) was found to be 2,5-dimethyl-3-nitro-1,4-benzoquinone(29c). Although the empirical formula of $C_8H_4NO_4$ was assigned to this product from the analytical data and the 1,4-benzoquinone structure was evident from the infra-red spectra, it was from the ^1H n.m.r. spectra that the assignment of structure (29c) was made in preference to structure (30c). The value for the long-range coupling between methyl groups and quinonoid protons in ^1H n.m.r. spectra are typically between 1.6 and 1.7 Hz[29]. Apparently such methyl groups are coupled significantly only with the adjacent proton[29]. Homo-allylic coupling has been observed in 2,3-dimethyl-1,4-benzoquinone (J_{23} = 1.3 Hz)[27]. As coupling was observed between a methyl group and the quinonoid proton (J = 1.5 Hz) in the ^1H n.m.r. spectrum of the product it was reasonable to assign them to adjacent carbons. The second methyl group was not coupled indicating that it could only be adjacent to the nitro

group. Hence the assignment of the structure (29c). Formation of the 1,4-benzoquinone (29c) from the phenol (28c) appears to mirror that of compounds (29a) and (29b), the mechanism for which is shown in Scheme 15.

The second product isolated was 2,5-dimethyl-3,6-dinitro-1,4-benzoquinone (44) (3%). The infra-red and ultra-violet spectra of compound (44) were very similar to those of compound (29c) above and the analytical data obtained indicated the molecular formula $C_8H_6N_2O_6$. Therefore the product was one of the dimethyldinitro-1,4-benzoquinones below:



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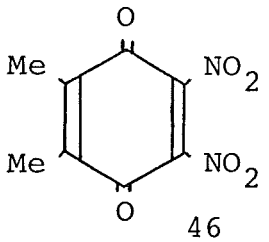

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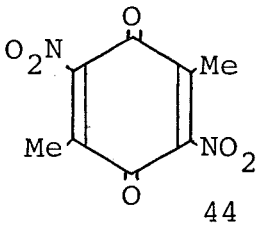


44

From comparison of the ^{13}C n.m.r. chemical shifts of the methyl group in several 1,4-benzoquinone structures (Figure 4), it can be seen that a methyl group adjacent to the nitro-group has a chemical shift in the order of δ11.0 to δ11.5, and that two adjacent methyl groups might be expected to have a chemical shift in the order of δ12.3. Therefore the structure of the product can be assigned as (44) or (45) on the basis of its methyl groups chemical shifts of δ11.4. Structure (45) was eliminated as a possibility after consideration of the structure of the starting material.

It appears that the minor product (44) obtained from the nitration of the phenol (28c) arises from the nitration-rearrangement (Scheme 15) of a reaction

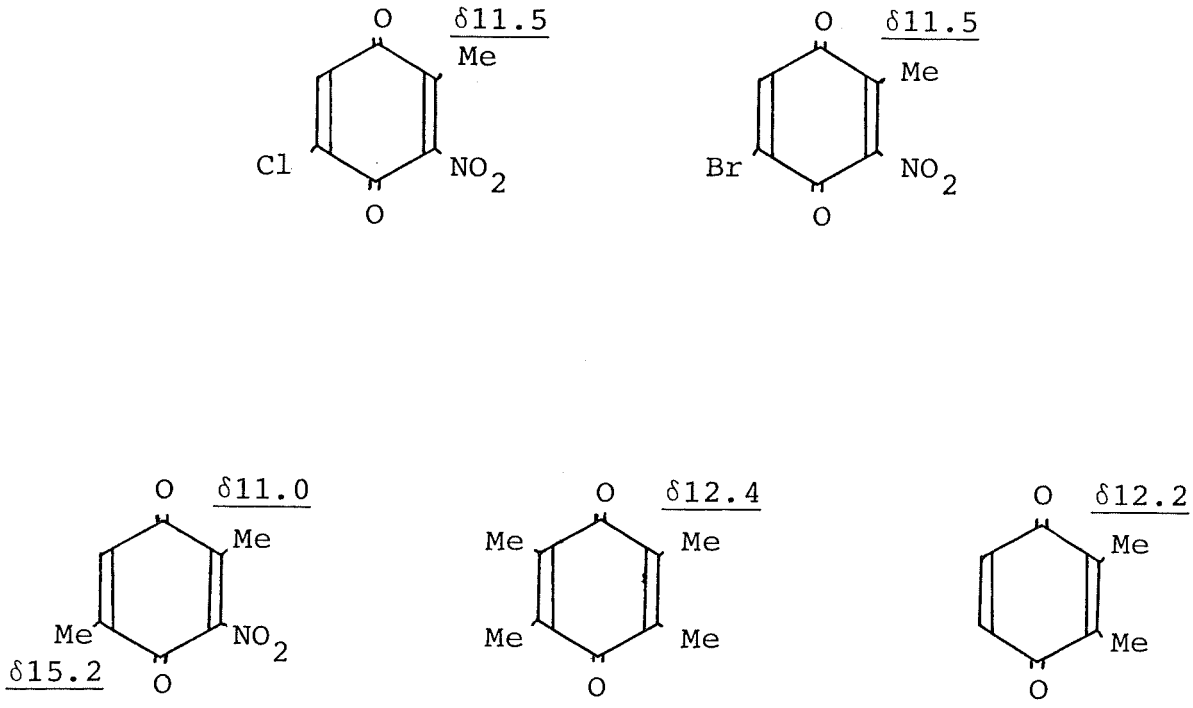
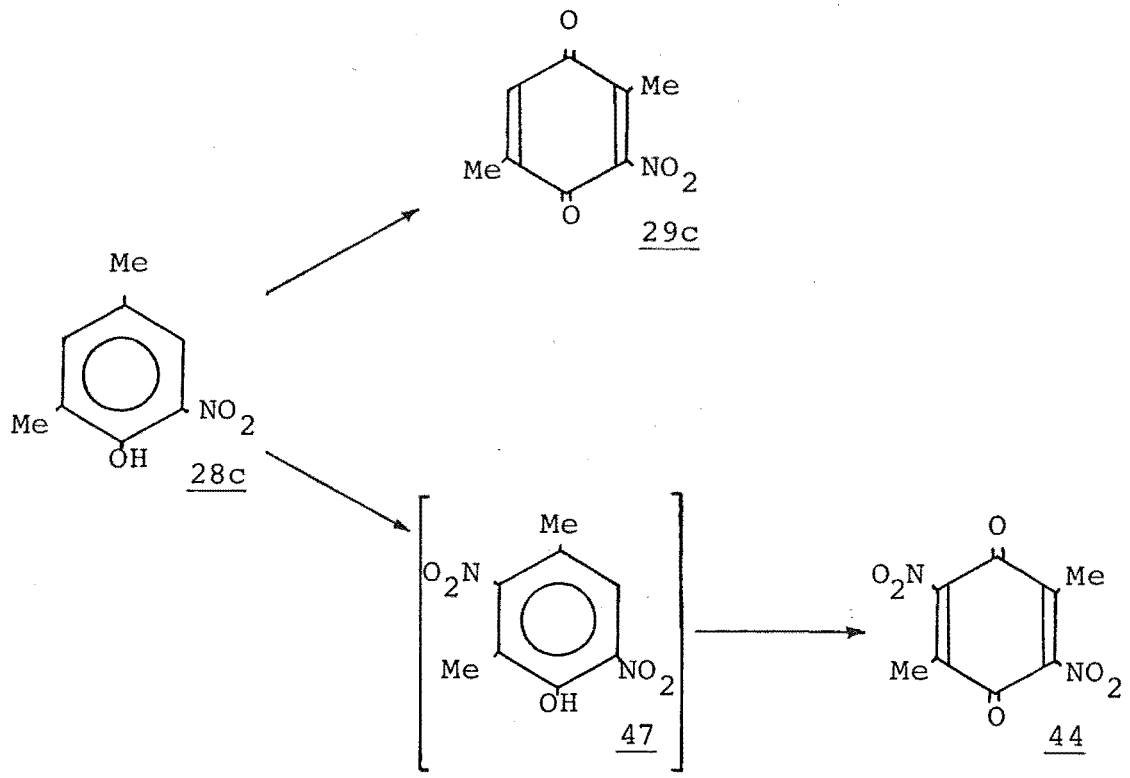


Figure 4

intermediate, 2,4-dimethyl-3,6-dinitrophenol(47); this compound is presumably formed by the nitration of the mononitrophenol (28c), Scheme 17. The possibility that the dinitro-1,4-benzoquinone(44) was formed by nitration of the mononitro-1,4-benzoquinone(29c) was excluded by a control experiment in which the mononitrobenzoquinone (29c) was treated under the same nitrating conditions as above, to give only the starting material (29c)(78%) with no trace of the dinitro-1,4-benzoquinone(44). The remaining material consisted of a complex mixture of highly polar oils.

In light of the formation of the 2-methyl-3-nitro-1,4-benzoquinones (29)(34) and (44) on treatment of the nitrophenols (28) and (32) with fuming nitric acid, this study was extended to examine the reactions of the

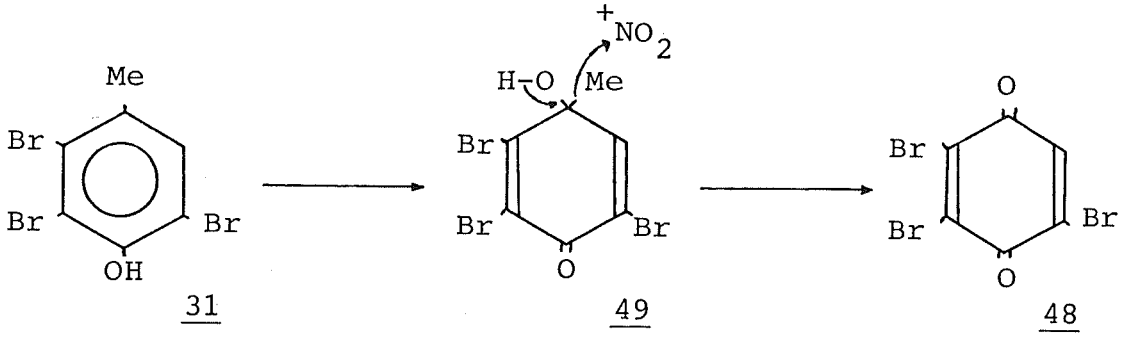
bromophenols (31) and (50); compounds in which the strongly electron-withdrawing 2-nitro group was absent.



Scheme 17

Nitration of the 2,3,6-tribromo-4-methylphenol(31), as for the phenols (28) above, gave the de-methylated product 2,3,5-tribromo-1,4-benzoquinone(48)(31%), identified from comparison of its melting point, 149-150° (uncorrected), with that quoted in the literature[30], 152-153°, and from the lack of a methyl peak in the ^{1}H n.m.r. spectrum. All the spectroscopic data obtained were in accord with the assigned structure (48). A similar yield (33%) of this de-methylated tribromo-1,4-benzoquinone(48) was also obtained by nitration of the 2,3,6-tribromo-4-hydroxy-4-methylcyclohexa-2,5-dienone(49) as above. The remaining material in both cases was highly polar oils.

Although the tribromophenol (31) reacts to form the 4-hydroxydienone (49) as shown in Scheme 15, a competing reaction then takes over from the usual acid-catalysed rearrangement. This competing reaction is believed to involve the attack of the methyl group by a nitronium ion to break the carbon-carbon bond as shown in Scheme 18, resulting in de-methylation. Only with compounds containing

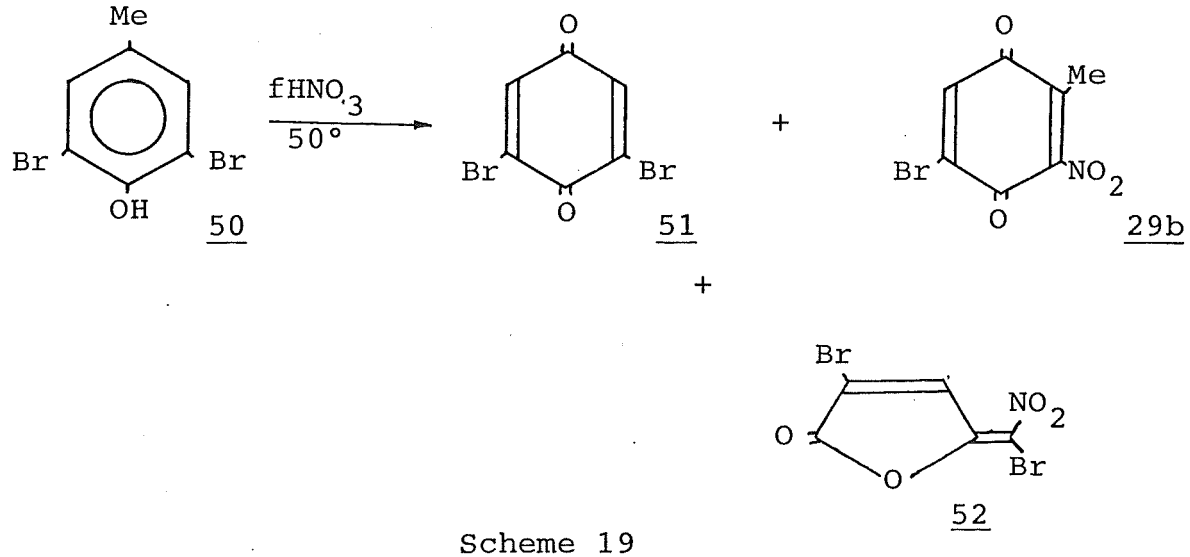


31 49 48

Scheme 18

the activating nitro group at the C6-position does reaction proceed by acid-catalysed rearrangement to form methyl-1,4-benzoquinones, Scheme 15.

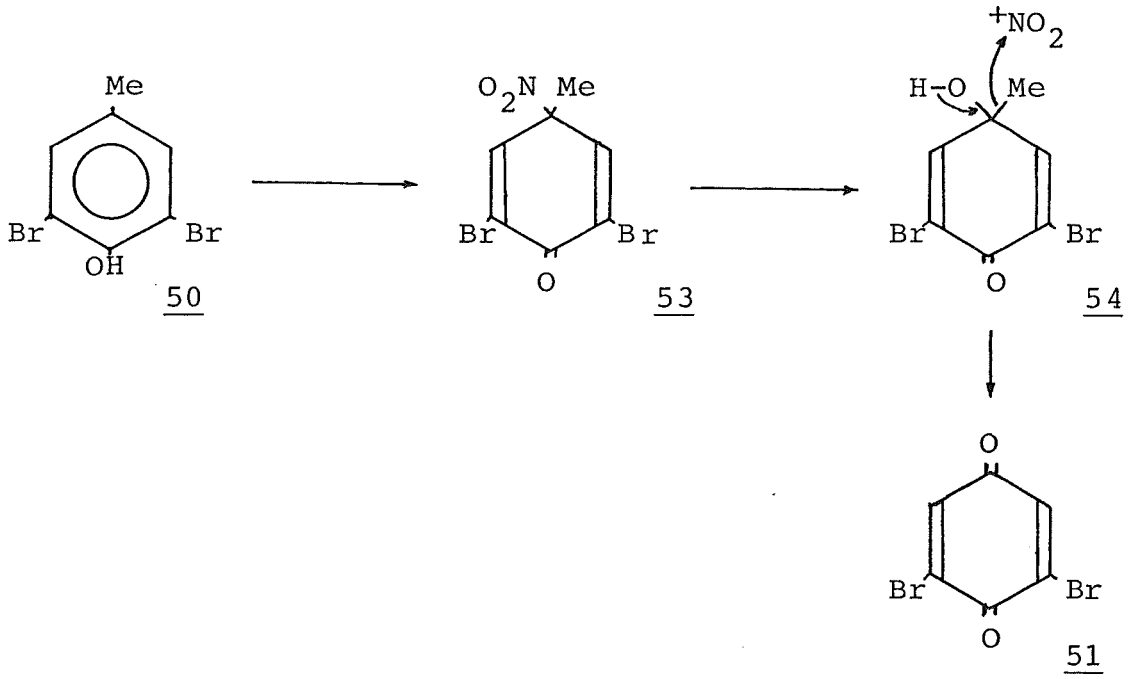
2,6-Dibromo-4-methylphenol (50) was nitrated as for the phenols (28) above, to give the de-methylated 2,6-dibromo-1,4-benzoquinone (51) (16%), the 5-bromo-2-methyl-3-nitro-1,4-benzoquinone (29b) (6%) and the furanone (52) (12%), in addition to a mixture of highly polar compounds, Scheme 19.



50 51 29b 52

Scheme 19

The dibromo-1,4-benzoquinone(51) was identified from its melting point and spectroscopic data by comparison with an authentic sample, prepared from the oxidation of 2,4,6-tribromophenol using fuming nitric acid at 0° as described by Hodgson *et al.*[31]. The mode of formation of this compound is believed to be similar to that of the tribromo-1,4-benzoquinone(48); the reaction proceeding *via* the 4-nitrodienone(53) to form the 4-hydroxy-dienone(54) which then loses its methyl group on attack by nitronium ion to form the 1,4-benzoquinone(51), Scheme 20.

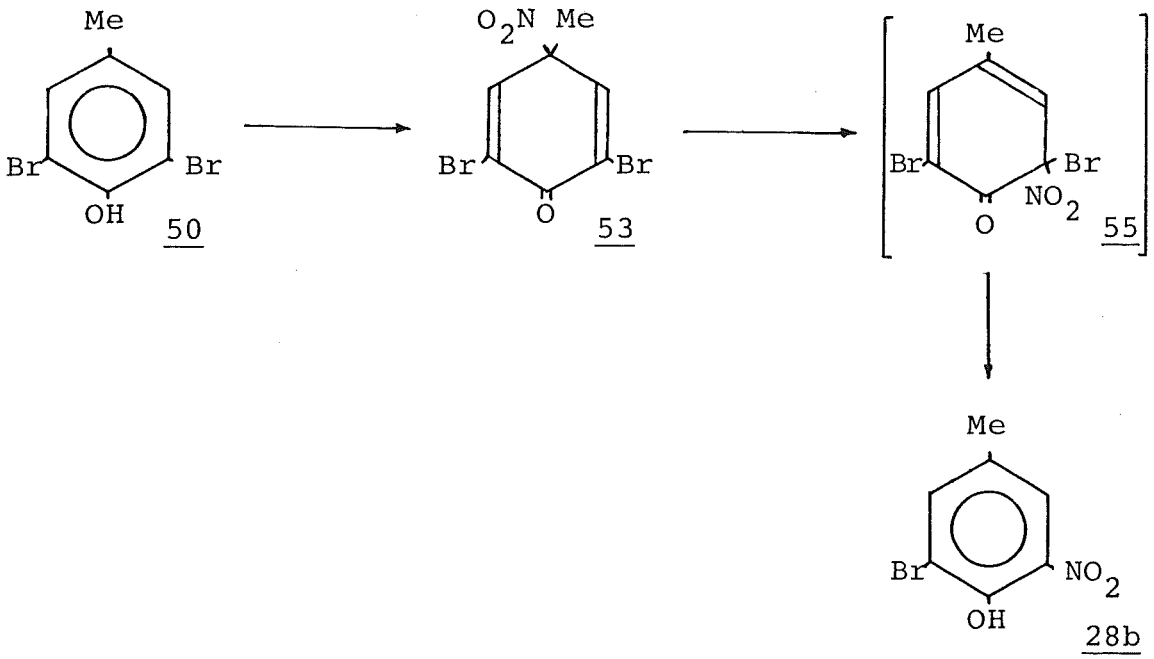


Scheme 20

The dibromo-1,4-benzoquinone(51) is also formed from nitration of both the 4-nitro (53) and the 4-hydroxy (54) dienones, consistent with the proposed reaction pathway.

The bromonitro-1,4-benzoquinone(29b) was similarly identified by comparison with an authentic sample prepared from the nitration of 2-bromo-4-methyl-6-nitrophenol(28b), as described above. It appears likely that the bromonitro-1,4-benzoquinone(29b) obtained from nitration of the

dibromophenol (50), was formed *via* the nitrophenol (28b). This phenol (28b) is probably formed by a nitration-de-bromination reaction involving the nitrodienones (53) and (55) as intermediates, Scheme 21; although a mechanism involving direct nitration of the phenol (50) to form the nitrophenol (28b) is possible with some regeneration of the phenol (50)



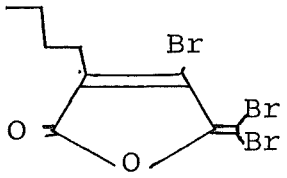
Scheme 21

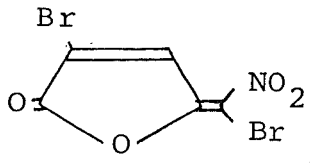
from the 4-nitrodienone (53). The bromonitro-1,4-benzo-quinone(29b) was also formed from nitration of the 4-nitrodienone (53), but not from the 4-hydroxydienone (54).

The furanone (52) had a carbonyl band at 1793 cm^{-1} in the infra-red spectrum which, along with the unusual ultra-violet spectrum of 253 nm, 344 nm (ε4,600, 16,200), suggested a completely different type of molecular structure to the compounds so far observed above. The structure of the compound was determined by single-crystal X-ray analysis as (z)-3-bromo-5-(bromonitromethylene)-2(5H)-furanone(52), $C_5HBr_2NO_4$. A perspective drawing of this molecule (52) is presented along with corresponding atomic

coordinates and other molecular dimensions in Appendix 2.

On re-evaluation of the spectroscopic data a close resemblance was noted between the compound and that of other lactones for which spectroscopic data were available[32]. The 1793 cm^{-1} carbonyl band in the infra-red spectra is characteristic of the lactone functional group, as is the ^{13}C n.m.r. chemical shift (δ162.6) for the carbonyl carbon, see Table 4[32].





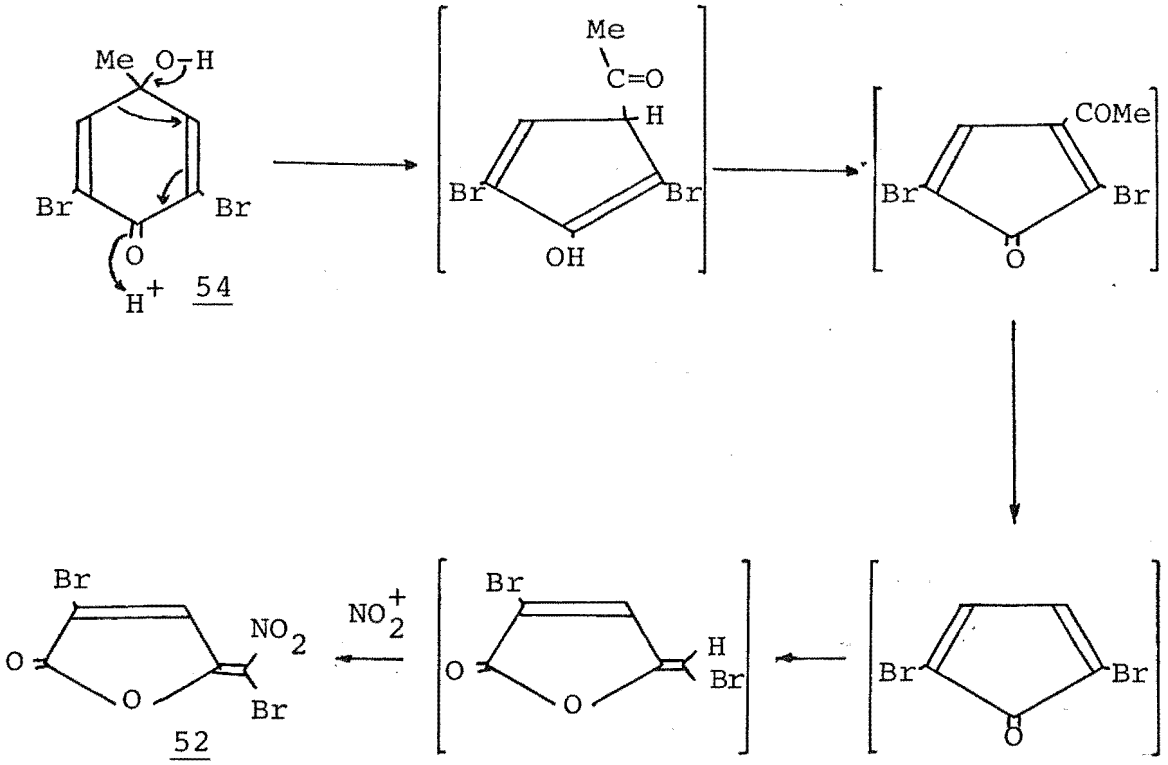
52

Infra-red specta	1790 cm^{-1}	1793 cm^{-1}
Ultra-violet spectra	308 nm (ε16000) (cyclohexane)	253,344nm(4,600, 16,000) ($CHCl_3$)
^{13}C n.m.r. spectra	($CDCl_3$)	(CD_3COCD_3)
2	δ164.8	δ162.6
3	138.1	122.8
4	128.4	140.4
5	144.7	156.5
6	81.4	117.3

Table 4

The furanone (52) was obtained by nitration of both 4-nitrodienone(53) and 4-hydroxydienone(54) suggesting that both these compounds are involved in the reaction pathway to the furanone from the phenol (50). However, the furanone

is not a product of the nitration of the 1,4-benzoquinone(51). A possible mechanism for the formation of the furanone is shown in Scheme 22. This mechanism is speculative, but it would account for the intermediacy of the hydroxydienone (54) and it avoids the necessity for the bromine atom migrations required by other mechanisms which were considered and rejected.



Scheme 22

In reviewing the results of the nitrations of phenols (28),(31),(32) and (50) with fuming nitric acid at 50°, comment must be limited because of the low accountability of these reactions in terms of identified products. However, it appears that the formation of the corresponding 4-hydroxy-4-methylcyclohexa-2,5-dienone, *via* the 4-nitrodienone, is a process common to all

reactions, above. In the presence of the activating electron-withdrawing nitro group, methyl-migration can then occur (Scheme 15). In the absence of a nitro group at C6, 1,4-benzoquinone formation occurs with loss of the C4-methyl group.

CHAPTER III

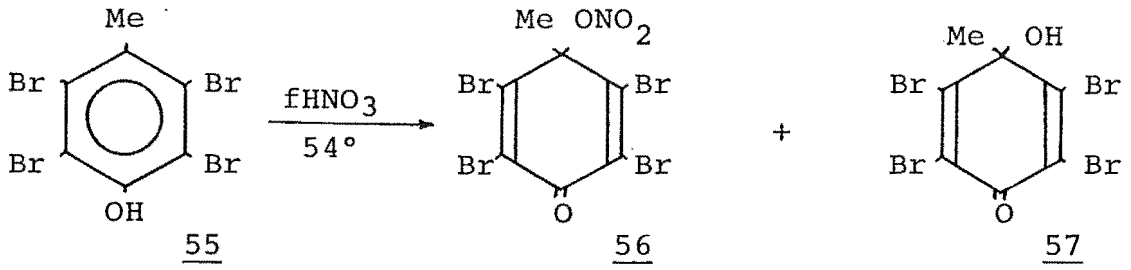
NITRATION OF TETRASUBSTITUTED 4-ALKYLPHENOLS

INTRODUCTION

As discussed earlier, nitration of the di- and tri-substituted 4-methylphenols using fuming nitric acid at 50° resulted in the formation of the corresponding 4-hydroxy-4-methylcyclohexa-2,5-dienone reaction intermediates which, depending on their substituents, either underwent acid-catalysed rearrangement with methyl-migration to form the corresponding 1,4-benzoquinone, Scheme 15, or underwent methyl loss to form the corresponding de-methylated 1,4-benzoquinone, Scheme 18. To extend this work we investigated the nitration of fully substituted 4-methylphenols under the same conditions as above.

DISCUSSION

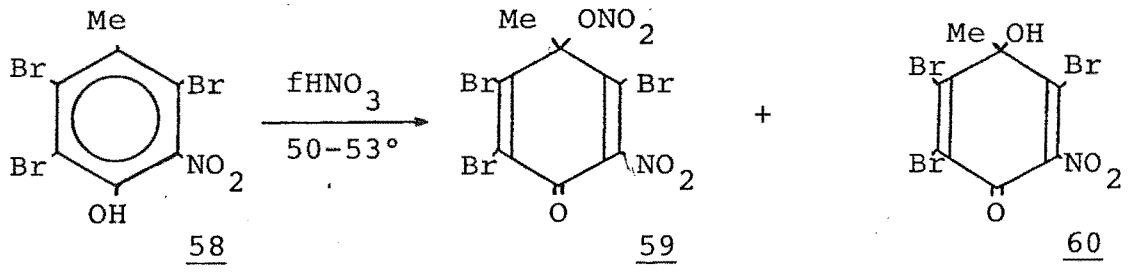
Nitration of the 2,3,5,6-tetrabromo-4-methylphenol(55) using fuming nitric acid at 54° gave the tetrabromo-4-methyl-4-nitratocyclohexa-2,5-dienone(56)(33%) and the corresponding 4-hydroxy-4-methyldienone(57)(41%) after separation of the crude product on a silica gel Chromatotron plate:



55 56 57

The tetrabromo-4-hydroxydienone (57) was identified by comparison with an authentic sample prepared according to the method described by Zincke *et al.*[33]. The tetrabromo-4-nitratodienone (56) was identified as an organic nitrate by its strong infra-red adsorption bands at 1657, 1276 and 824 cm^{-1}. The ultra-violet and n.m.r. spectra of this compound (56) were similar to those for the corresponding 4-hydroxydienone (57) and the analytical data for the compound (56) was in accord with that required for a molecular formula of $C_7H_3Br_4NO_4$. The tetrabromo-4-nitratodienone (56) was also prepared in 29% yield by treatment of the tetrabromo-4-hydroxydienone (57) with fuming nitric acid under the same conditions as above.

Nitration of the 2,3,5-tribromo-4-methyl-6-nitrophenol (58), as for the tetrabromophenol (55), gave both the corresponding 4-nitratodienone (59) (27%) and 4-hydroxydienone (60) (56%):



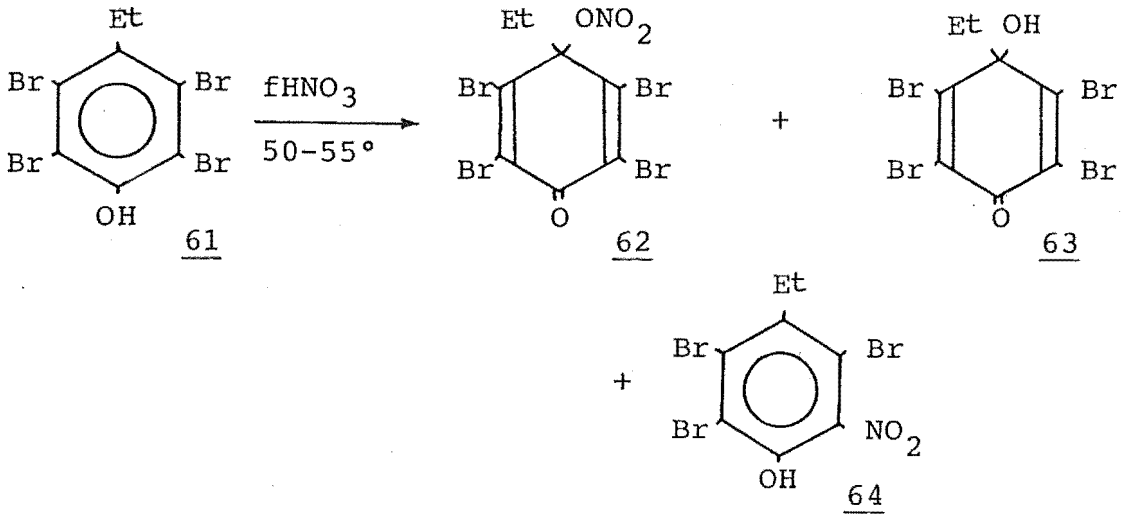
58 59 60

The tribromonitro-4-hydroxydienone (60) was identified by

comparison with an authentic sample prepared according to the standard method described by Zincke[33]. The tribromonitro-4-nitratodienone(59) was identified in the same way as the nitrate(56) above. Analytical data confirmed the molecular formula of $C_7H_3Br_3N_2O_6$. The tribromonitro-4-nitratodienone (59) was also prepared in 43% yield by treatment of the corresponding 4-hydroxydienone(60) with fuming nitric acid under the same conditions as above.

Both 4-hydroxydienones(57) and (60) were formed on nitration of the fully-substituted 4-methylphenols(55) and (58) *via* the corresponding 4-methyl-4-nitrodienones. But instead of rearranging to give substituted 1,4-benzoquinones as observed for the di- and tri- substituted 4-methylphenols above, a competing esterification-nitration occurred to give the 4-nitratodienones(56) and (59). As an ethyl group has a greater migratory aptitude than a methyl group, it was decided that the above nitration reactions should be repeated with the 4-ethyl analogues compounds (61) and (64). Here we hoped to get the acid-catalysed rearrangement of the 4-hydroxydienone intermediates to give the corresponding 1,4-benzoquinones.

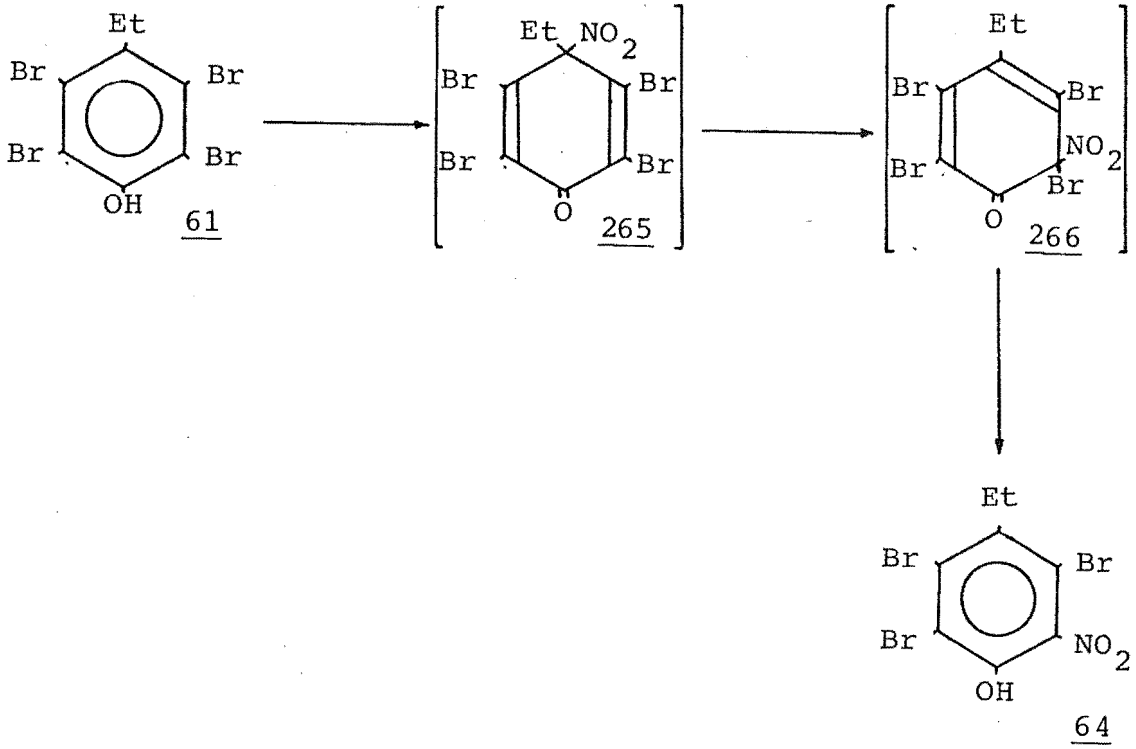
Nitration of the tetrabromo-4-ethylphenol(61), as for the phenol (55), gave the tetrabromo-4-ethyl-4-nitratodienone(62)(17%), the tetrabromo-4-ethyl-4-hydroxy-dienone(63)(63%) and tribromo-4-ethyl-6-nitrophenol(64)(5%). The tetrabromo-4-hydroxydienone(63) was identified by comparison of its spectroscopic data with that of an authentic sample prepared according to the standard method. The corresponding 4-nitratodienone(62) was identified as for the nitratodienones above. Its



molecular formula of $C_8H_5Br_4NO_4$ was confirmed from its analytical data. The final product (64) was identified from comparison of its spectroscopic data with that of an authentic sample prepared by sodium nitrate treatment of the tetrabromo-4-ethylphenol(61) suspended in acetic acid.

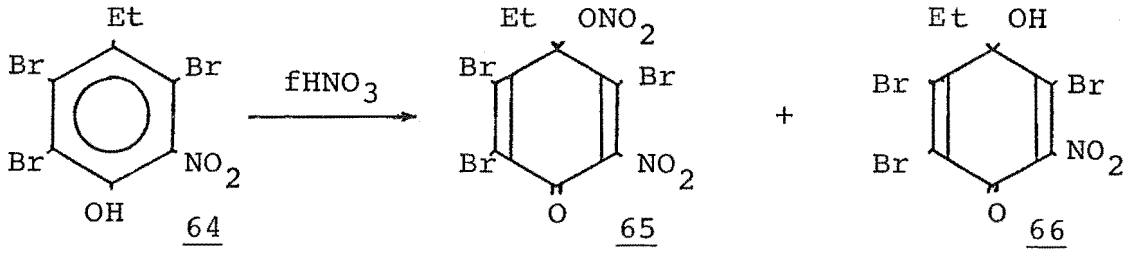
It is uncertain whether this product (64) obtained from the nitric acid solution was formed by direct nitration of the tetrabromo-ethylphenol(61) at the C6-position, or by rearrangement of the tetrabromo-4-ethyl-4-nitrodienone intermediate (265) to give the 6-nitrocyclohexa-2,4-dienone (266) which could then lose the C6-bromine atom to give the product (64), Scheme 23. The tetrabromo-4-ethyl-4-nitratodienone(62) was also prepared in 52% yield by reaction of the corresponding 4-hydroxydienone(63) with fuming nitric acid under the same conditions as above. In this case no other product (other than starting material) was obtained.

Nitration of the 2,3,5-tribromo-4-ethyl-6-nitrophenol(64), as for the phenol (55), gave the 2,3,5-tribromo-4-ethyl-4- nitrato-6-nitrodienone(65)(25%) and the



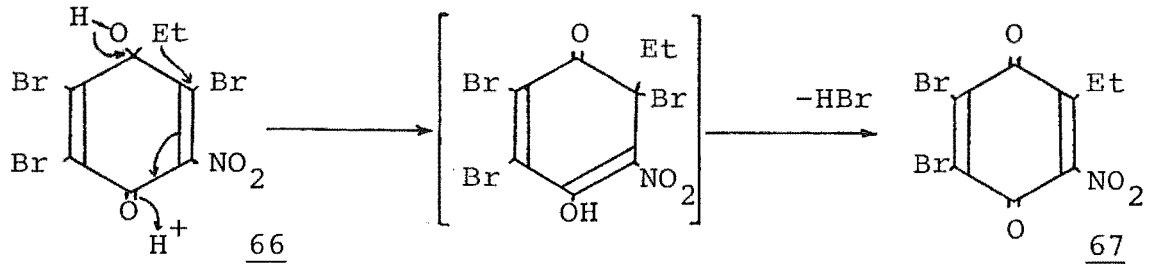
Scheme 23

corresponding 4-hydroxydienone(66)(59%). Both of these compounds were identified as for compounds (62) and (63) above; their spectroscopic data are tabulated in Appendix 5:



Treatment of the tribromo-4-ethyl-4-hydroxy-6-nitrodienone (66) with fuming nitric acid, as for the phenol (64), gave the corresponding 4-nitratodienone(65)(44%) and the 2,3-dibromo-5-ethyl-6-nitro-1,4-benzoquinone(67)(2%) in addition to recovered hydroxydienone(66)(43%). The 1,4-benzoquinone(67) was identified by comparison of its

spectroscopic data with those of an authentic sample prepared from the sulphuric acid treatment of the 4-hydroxy-dienone(66) (discussed later). The quinone (67) is believed to be formed *via* the mechanism shown in Scheme 24. The acid-catalysed rearrangement probably occurs in this



Scheme 24

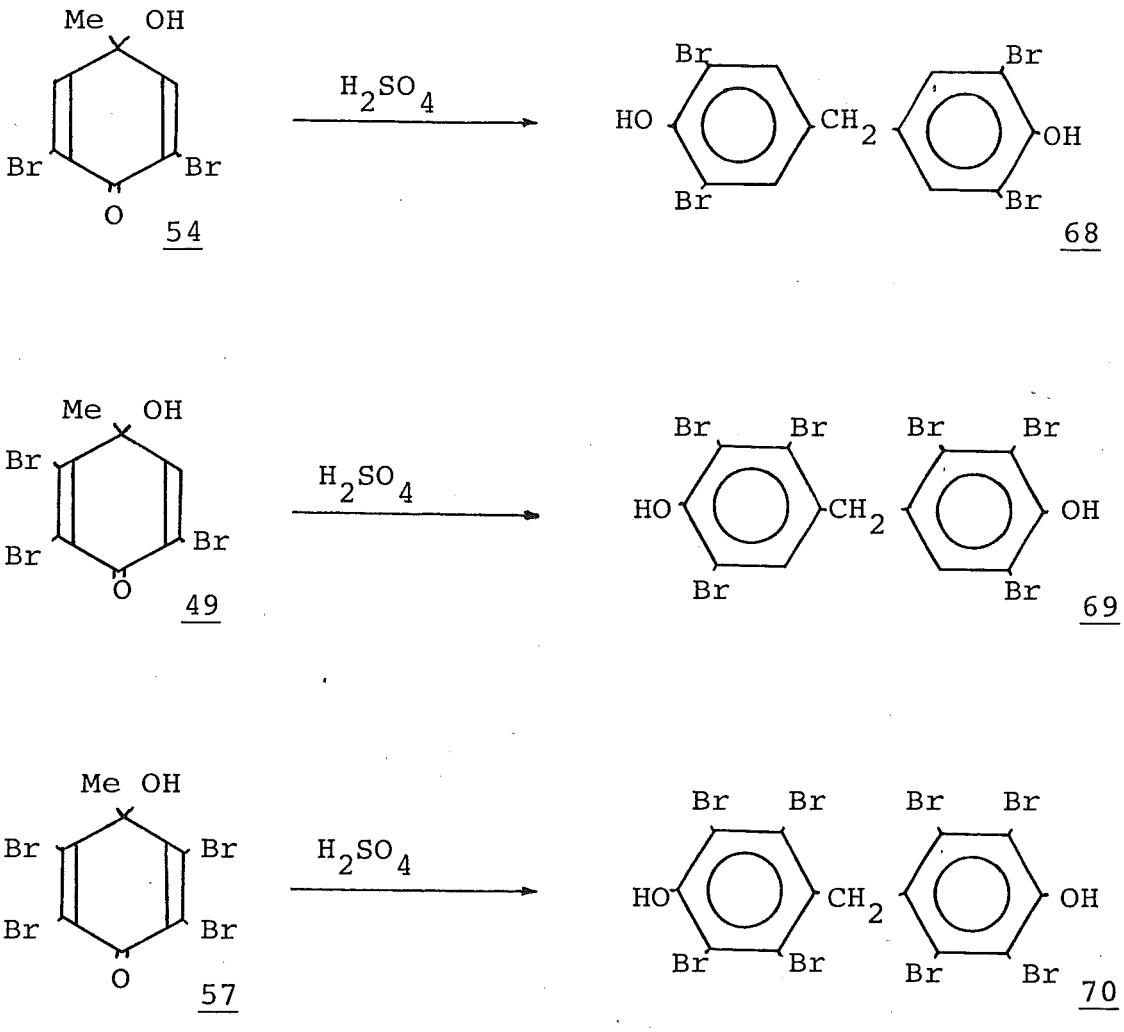
case because of the greater migratory aptitude of the ethyl group as compared to the methyl group, and because the electron-withdrawing nitro group is present to enhance migration of the ethyl group to the β-position, C5.

CHAPTER IV

SULPHURIC ACID TREATMENT OF THE 4-HYDROXYCYCLOHEXA-2,5-DIENONES

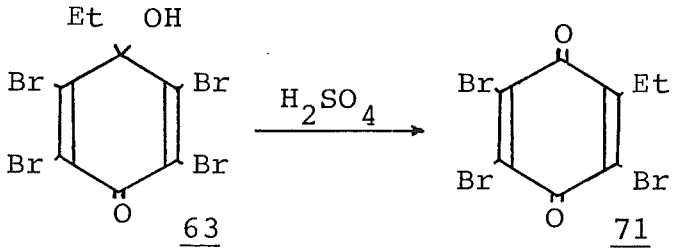
INTRODUCTION

Zincke *et al.*[33] reported the reaction of the 2,6-dibromo-(54), the 2,3,6-tribromo-(49) and the 2,3,5,6-tetrabromo-(57) 4-hydroxy-4-methylcyclohexa-2,5-dienones with concentrated sulphuric acid to give the



Scheme 25

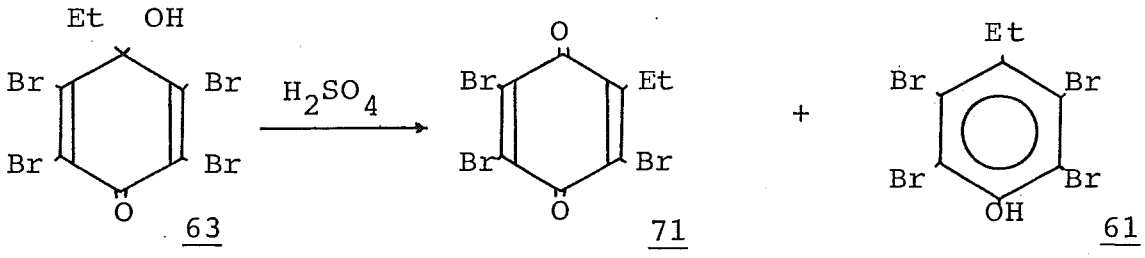
diphenylmethanes(68), (69) and (70), Scheme 25. It appears that the product assignments above were made on the basis of the analytical data obtained from the octobromo compound (70). Analytical data were not reported for the other two compounds (68) and (69). Zincke *et al.*[34] also reported the reaction of the 2,3,5,6-tetrabromo-4-ethyl-4-hydroxydienone(63) with concentrated sulphuric acid to give the 1,4-benzoquinone(71):



63 71

DISCUSSION

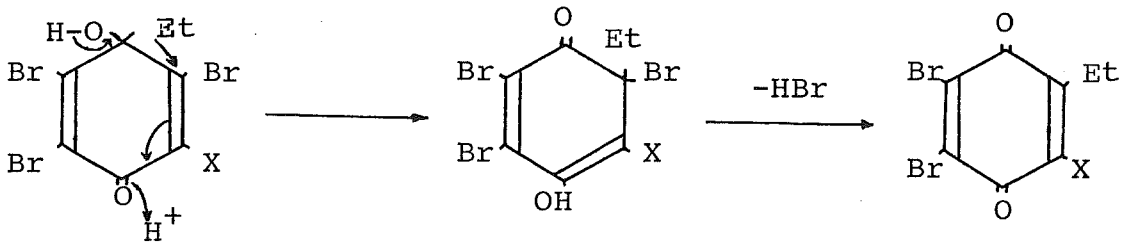
Repetition of the sulphuric acid treatment of the tetrabromo-4-ethyl-4-hydroxydienone(63) gave the 2,3,6-tribromo-5-ethyl-1,4-benzoquinone(71)(54%) and the tetrabromo-4-ethylphenol(61)(27%):



63 71 61

The phenol (61) was identified from comparison of its spectroscopic data with that of an authentic sample prepared from the bromination of 4-ethylphenol. The 1,4-benzoquinone(71) was identified from its infra-red spectrum absorption bands at 1678 and 1664 cm^{-1} (Carbonyl), and from its melting point of 117-118° which corresponded with that reported by Zincke[34] (118-120°) for the structure assigned (71). The ^{13}C n.m.r. spectrum supported this assignment, Appendix 5.

The formation of the tribromo-1,4-benzoquinone(71) provided evidence for the acid-catalysed rearrangement which was believed to occur with 4-alkyl-4-hydroxycyclohexa-2,5-dienones in fuming nitric acid, Scheme 15. This rearrangement (Scheme 26) clearly demonstrates the acid-catalysed rearrangement postulated for some nitric acid reactions. The formation of the tetrabromo-4-ethylphenol(61)



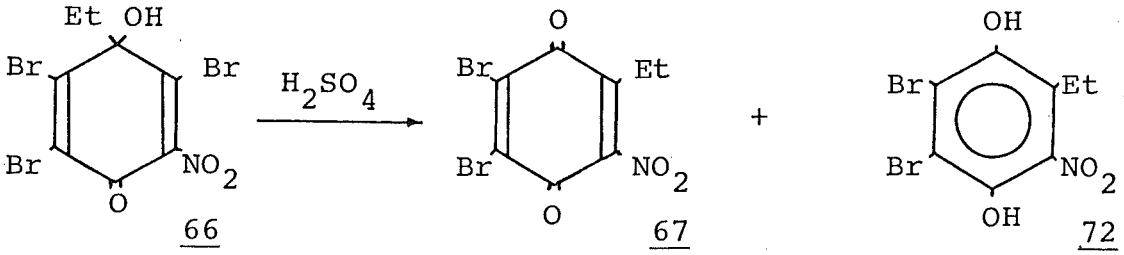
X = Br
= NO_2

Scheme 26

from the corresponding 4-hydroxydienone(63) required a reduction step.

The 2,3,5-tribromo-4-ethyl-4-hydroxy-6-nitrodienone(66) was also treated with concentrated sulphuric acid and gave

the 2,3-dibromo-5-ethyl-6-nitro-1,4-benzoquinone(67) (52%) and its corresponding hydroquinone(72) (34%):



66 67 72

The 1,4-benzoquinone structure (67) was assigned to one of the products after comparison of the similarities in its spectroscopic data with those of the tribromo-1,4-benzoquinone(71), Appendix 5. Analytical data for the product (67) was in agreement with that required for a molecular formula of $C_8H_5Br_2NO_4$. The hydroquinone structure (72) was assigned to the other product after comparison of its spectroscopic data with that of an authentic sample prepared from the reduction of the dibromonitro-1,4-benzoquinone(67) using stannous chloride.

The formation of the dibromonitro-1,4-benzoquinone(67) is believed to occur *via* an acid-catalysed rearrangement as shown in Scheme 26. The activating-directing effect of the nitro group induced the migration of the ethyl group to proceed to the C5-position. The corresponding 1,4-hydroquinone(72) may be formed by reduction of the 1,4-benzoquinone(67) under the conditions of the reaction.

Repetition of the treatment of the tetrabromo-4-hydroxy-4-methyldienone(57) using concentrated sulphuric acid at 20° for 16 hours gave, on addition of ice/water, a white powder. The infra-red spectrum of the product was similar (but not the same) as that of the tetrabromo-

4-methylphenol(55). The structure (73) was assigned to this product on the basis of its spectroscopic data and its elemental analysis. The ^{1}H n.m.r. signal at δ5.12 and ^{13}C n.m.r. signal at δ68.7 are characteristic of the benzenemethanol structure. Comparison of the spectroscopic data reported for the methylene function of benzenemethanol (^{1}H n.m.r.($CDCl_3$) δ4.70, CH_2 and ^{13}C n.m.r.($CDCl_3$) δ64.7, CH_2)[60] with those reported for diphenylmethane (^{13}C n.m.r.($CDCl_3$) δ41.90, CH_2)[61] and diphenylethane (^{13}C n.m.r.($CDCl_3$) δ37.90, CH_2)[62] support this assignment. The elemental analysis for compound (73) was in agreement with the assigned structure (Table 5). Furthermore a comparison of the observed ^{13}C n.m.r. spectrum with that calculated[28] for the proposed structure supported the above structural assignment, Table 5a.

Analytical Data for Product (73)		
C	H	Br
19.2%	1.1%	72.1%
19.1%	1.1%	72.3%
19.3%	1.0%	72.2%
19.2%	0.8%	72.5%

Calculated Compositions				
	C	H	Br	N
$C_7H_4Br_4O_2$	19.1%	0.9%	72.7%	-
$C_7H_4Br_3NO_4$	20.7%	1.0%	59.1%	3.5%

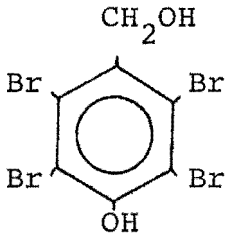
Analytical Data for Product (75)			
C	H	Br	N
20.9%	0.9%	58.2%	3.3%

Table 5

The mechanism for the formation of the benzenemethanol (73) is believed to involve an acid-catalysed dehydration of the hydroxydienone (57) to form a quinonemethide. Addition of sulphuric acid to this quinonemethide would yield as ester which on hydrolysis during workup, would give the benzene-

methanol derivative (73), Scheme 26b.

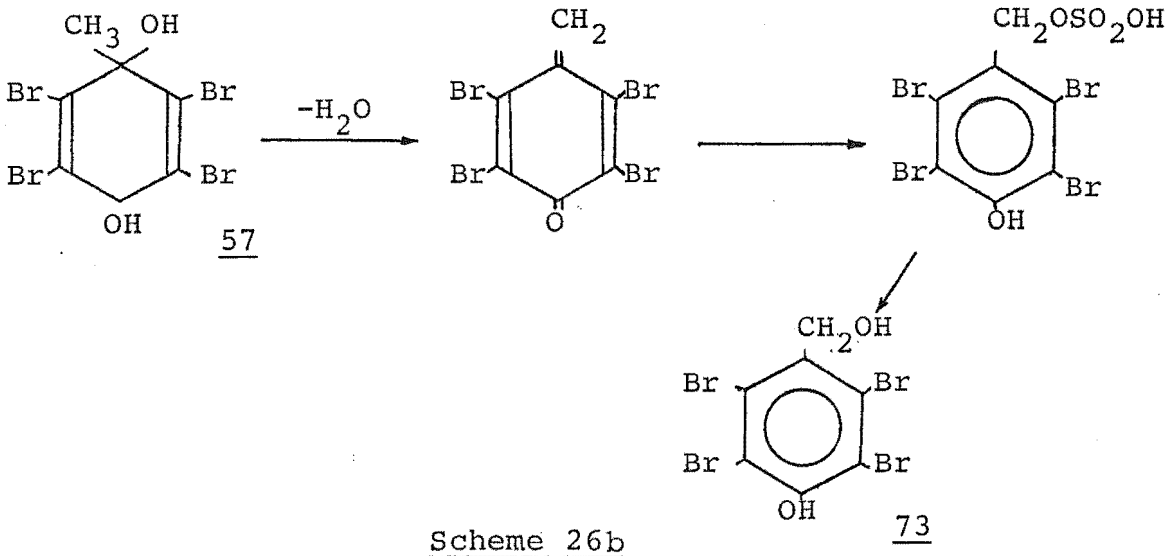
Calculated ^{13}C n.m.r. Chemical Shifts[28]



73

	Calculated	Observed
1	143.4	134.3
2	126.9	128.5
3	113.8	115.3
4	164.6	153.3
5	113.8	115.3
6	126.9	128.5

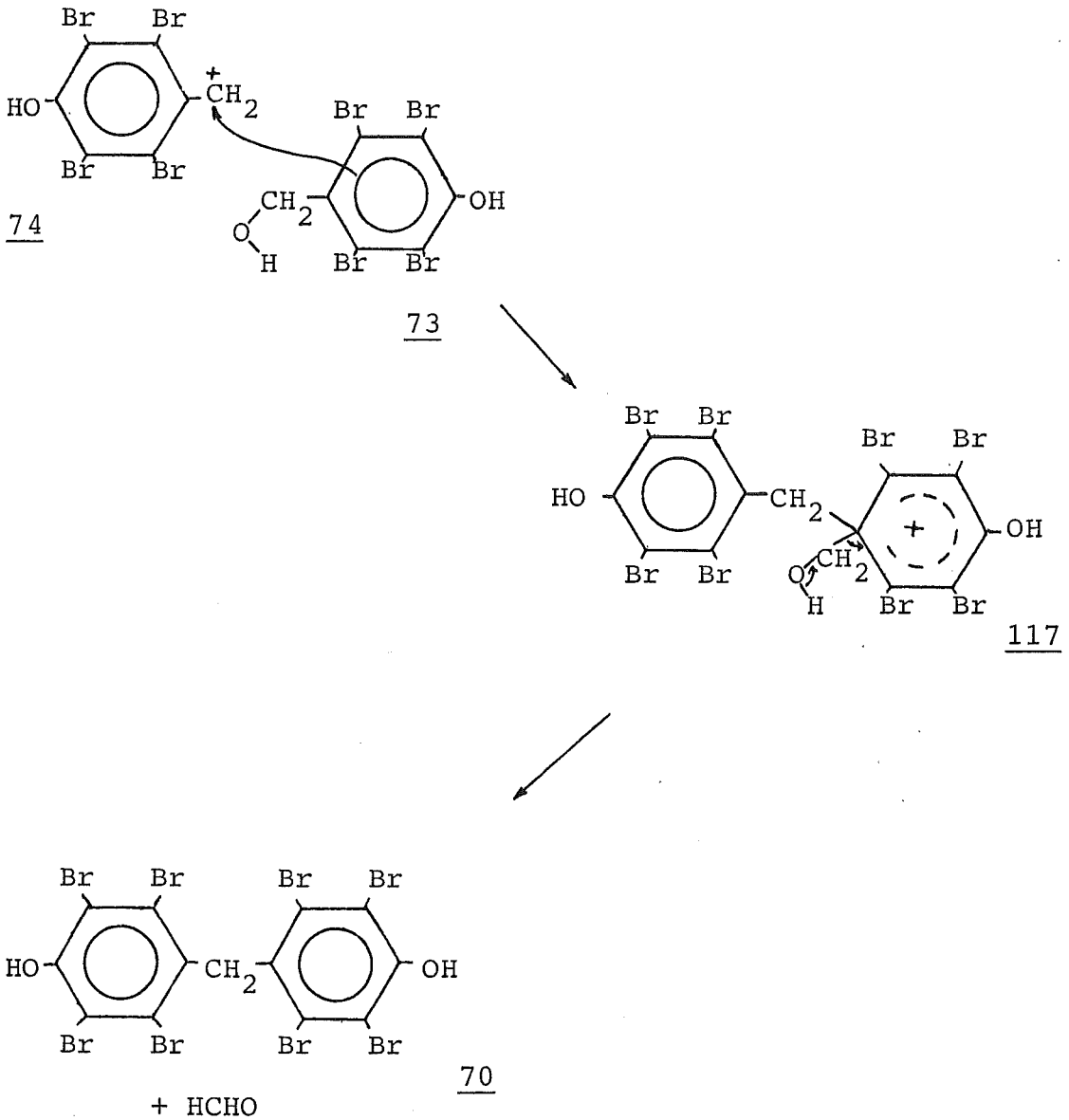
Table 5a



Scheme 26b

The benzenemethanol product (73) melted with decomposition on heating to 175-180°. On further heating the sample resolidified and then melted again at 270° (dec.). This final melting point is just below the melting point quoted by Zincke and Böttcher[63] (m.p. 280-281° (dec.)) for the purified diphenylmethane(70) also prepared from the hydroxydienone(57), but on reaction with warm conc. sulphuric acid.

We now believe that the product (73) is an intermediate not previously isolated by Zincke *et al.*[63] due to the more vigorous reaction conditions employed by those authors. On heating alone or with warm conc. sulphuric acid the intermediate benzenemethanol(73) is believed to form the diphenylmethane(70) *via* the mechanism shown in scheme 27. Reaction of the benzylic cation (74) *ipso* to the $-CH_2OH$ function of a second benzenemethanol molecule would give the Wheland



Scheme 27

intermediate(117). Loss of formaldehyde from this intermediate (117) would yield the observed substituted diphenylmethane(70). Similar behaviour has been reported by Zincke and Hünke[64] for the analogous tetrachloro compounds.

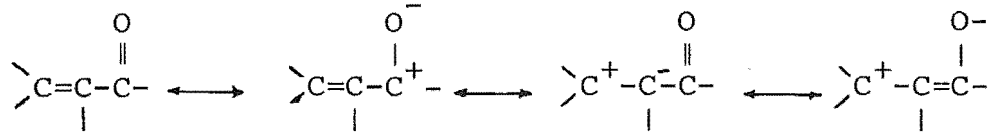
2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone(60) was also treated with concentrated sulphuric acid at 20° for 25 minutes. Separation of the crude product on a silica gel Chromatotron plate gave an unidentified product (28%) which recrystallised from ether-petroleum ether as orange-red needles of melting point 143-144°. This material gave a high resolution mass spectrum parent ion pattern corresponding to $C_7H_5NO_4Br_2^{79}$ (±6 ppm). Some starting material was also recovered, as was a compound tentatively assigned the 2,3,6-tribromo-4-hydroxy-5-nitrobenzenemethanol(75)(18%) structure. The elemental analysis for compound (75) was not entirely satisfactory (Br analysis c. 0.9% too low), but further investigation of this, (75), and the product of unknown structure, above, was precluded by the lack of further material.

CHAPTER V

NUCLEOPHILIC REACTION OF TETRASUBSTITUTED HYDROXYCYCLOHEXA-2,5-DIENONES

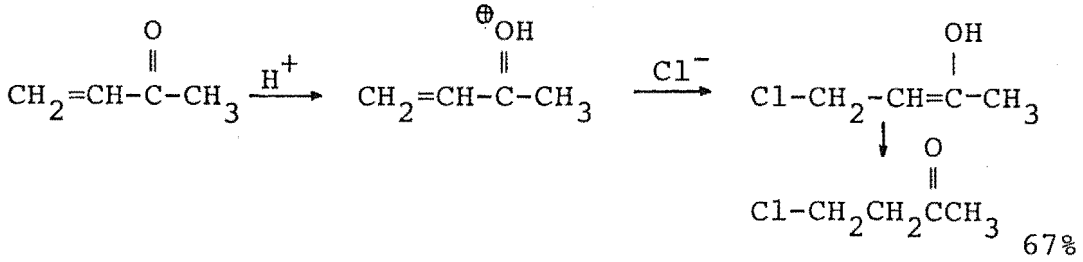
INTRODUCTION

A carbonyl group and a carbon-carbon double bond in conjunction act as a single functional group. The electronic structure of such substances may be represented by the following resonance forms:

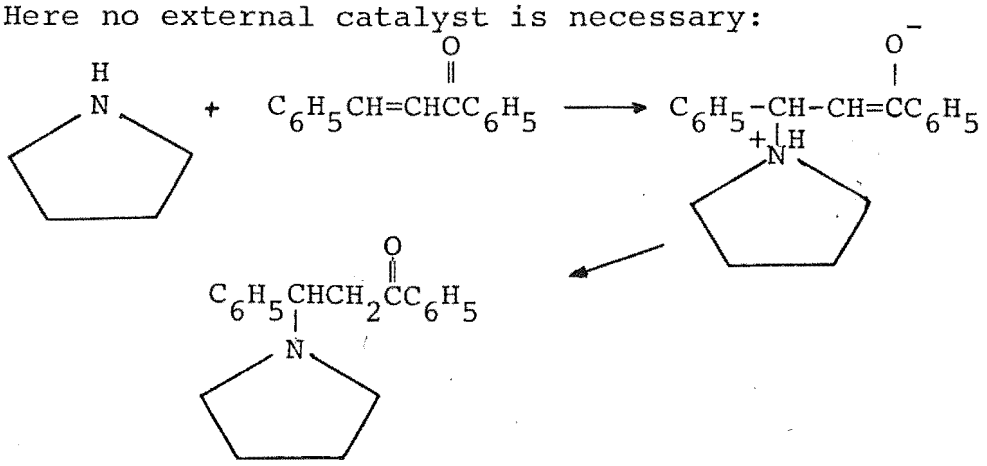


The addition of electrophilic reagents to these α,β-unsaturated carbonyl functions is greatly reduced, but nucleophilic addition is greatly enhanced, and may occur at either the carbonyl carbon or at the β-carbon, or as a mixture of these depending on steric and electronic factors and on the conditions of reaction. Like simple additions to carbonyl groups, conjugate addition may be achieved with either base (or direct nucleophilic) or acid-catalysis.

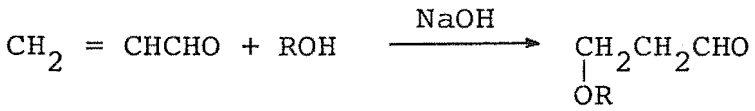
Hydrogen halides add readily to the carbon-carbon double bonds of α,β-unsaturated aldehydes and ketones. An example of this is shown below:



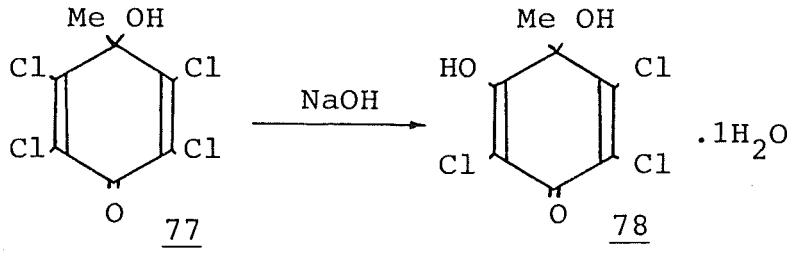
Similar attack may occur with the addition of an amine. Here no external catalyst is necessary:



Similar reaction with alcohols occurs with base catalysis:



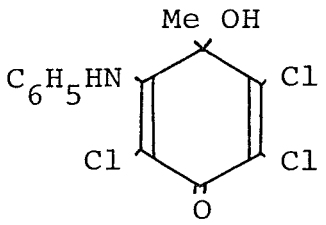
Zincke investigated the effect of nucleophilic attack on the conjugated carbonyl systems in the substituted 4-hydroxy-4-methylcyclohexa-2,5-dienones. When Zincke *et al.*[25] treated 2,3,5,6-tetrachloro-4-hydroxy-4-methyl-cyclohexa-2,5-dienone(77) with sodium hydroxide solution, he reported that substitution occurred at the β-carbon to give the trichlorodihydroxy compound (78) which recrystallised as the hydrate:



77 78

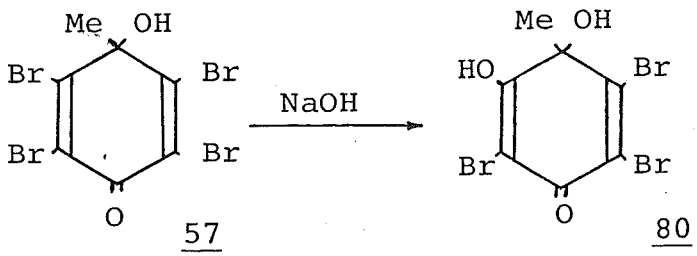
Scheme 30

Reaction of the same tetrachloro compound (77) with aniline gave the compound (79) below:



79

Similar reactions were reported[33] to occur on treatment of the analogous tetrabromo compound (57) with sodium hydroxide or with aniline. The tribromodihydroxy product (80) obtained from the reaction of the compound (57) with sodium hydroxide was reported to recrystallise from



57 80

ether-petroleum ether as hydrated crystals of melting point 131°, but by heating at 70-80° under vacuum, these could be dehydrated to give crystals of melting point 152°.

DISCUSSION

In the last chapter it was seen that the methyl-migration that occurred on nitrating substituted 4-methyl-phenols to form 1,4-benzoquinones, proceeded *via* acid-catalysed rearrangement of the corresponding 4-hydroxy-4-methylcyclohexa-2,5-dienone intermediate as shown in Scheme 15. This migration can be viewed as a nucleophilic attack by the methyl group, Figure 7. In order to follow

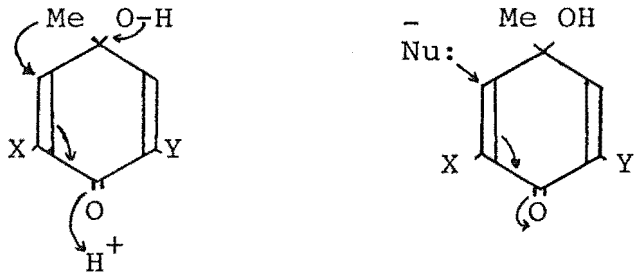


Figure 7

up the work already undertaken in this area, it was decided that an investigation of nucleophilic attack on the substituted 4-hydroxy-4-methylcyclohexa-2,5-dienones should be undertaken.

To this end the tetrabromo-4-hydroxydienone(57) was added to a 10% aqueous solution of sodium hydroxide containing some ethanol. After an hour at 20° the solution was acidified to give a white precipitate of the dihydroxy compound (80). This compound was recrystallised from chloroform and gave two crystalline forms; the first melted at 154-155° and the second melted at 173-175°. The two crystalline forms had identical nujol-mull infra-red spectra and solution spectra. The infra-red contained two strong bands at 1598 and 1562 cm^{-1} resulting from the carbon-carbon double bonds, and three bands at 3560, 3480 and 3320 cm^{-1}

due to the oxygen-hydrogen stretching mode of the hydroxyl groups. The bands above were all consistent with those observed in most 4-hydroxy-4-methylcyclohexa-2,5-dienone systems, although those bands corresponding to the carbon-carbon double bonds were considerably stronger than expected, possibly due to resonance characteristics of the keto-enol system. The carbonyl group absorbed at 1608 cm^{-1} as compared with the starting materials carbonyl absorbance at 1675 cm^{-1}. This lower frequency indicates a weaker carbon-oxygen double bond as would be expected if strong hydrogen bonding was present between the carbonyl oxygen and another hydrogen atom (Figure 8A) and/or if resonance within the conjugated carbonyl system was present (Figure 8B).

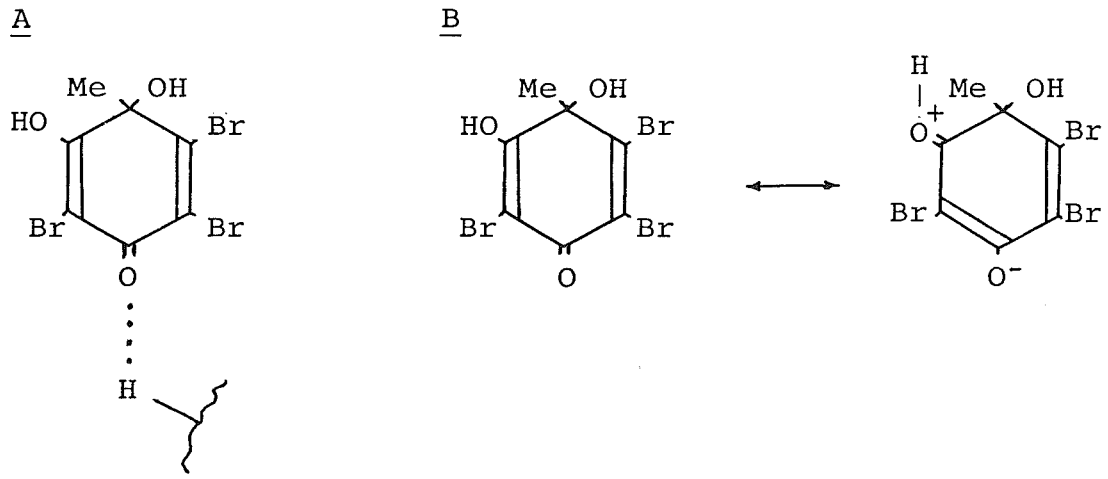


Figure 8

The solution spectra for compound (80) were consistent with those of other compounds with similar structures. The ultra-violet spectrum exhibited the usual cyclohexa-2,5-dienone pattern with absorbances at 259 and 312 nm (ε 16100, 3630); and the ^{13}C n.m.r. spectrum had the usual chemical shifts associated with keto-enol systems[35], Figure 9.

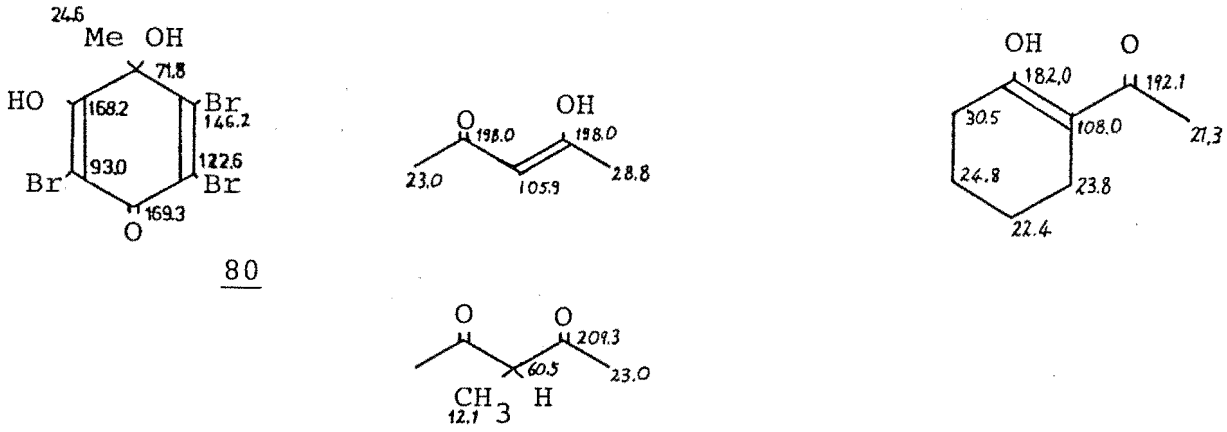


Figure 9

In order to investigate the structure of this compound more closely particularly with regard to the interactions between the water molecule and the hydroxyl groups, it was decided that a single crystal X-ray crystallographic analysis should be undertaken. The X-ray analysis was carried out on the more common 154-155° melting form of the product and was found to have the structure (80) with the bond lengths shown in Figure 10. Note that all oxygen-hydrogen bonds were fixed at 0.96 Å during the refinement process and this may make the hydrogen bonds observed appear longer than is really the case.

The 1.90 Å hydrogen bond between the water hydrogen atom and the C4-oxygen atom probably has little effect on the structure or the spectra of the compound (80). However, the other two hydrogen bonds may well increase the resonance effects in the keto-enol system by the process shown in Figure 11. Resonance of this sort would be expected to shorten the C1-C2 bond and lengthen the C2-C3 bond as is observed, Figure 10. This feature is

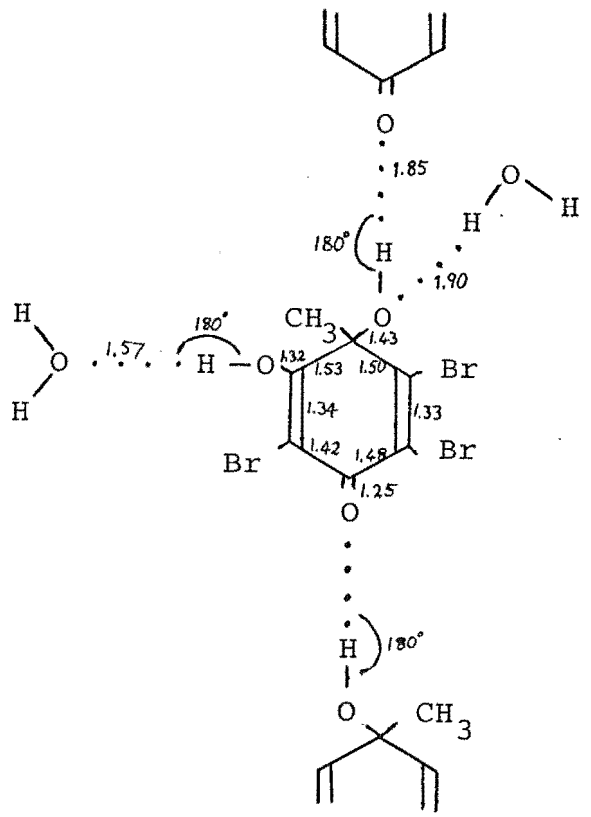


Figure 10

reflected in the low frequency carbonyl absorbance band observed in the infra-red spectra discussed earlier. Perspective drawings of the molecule (80) are presented along with corresponding atomic coordinates and other molecular dimensions in Appendix 3.

Treatment of the tetrachloro-4-hydroxy-4-methyldienone (77) with 6% aqueous sodium hydroxide solution for 1 hour at 20° was found to yield only starting material. Only after heating the solution at 38-44° for 30 minutes was reaction observed to occur to give the trichlorodihydroxy

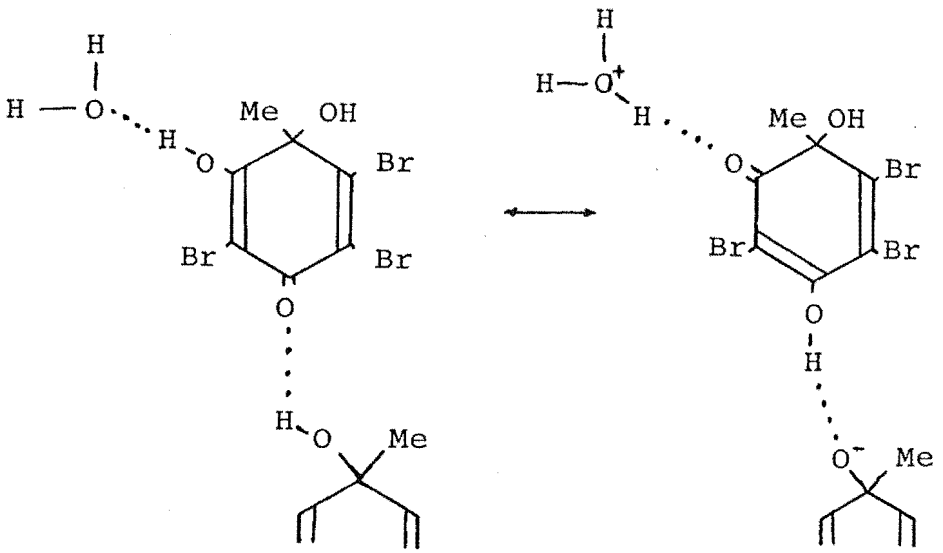
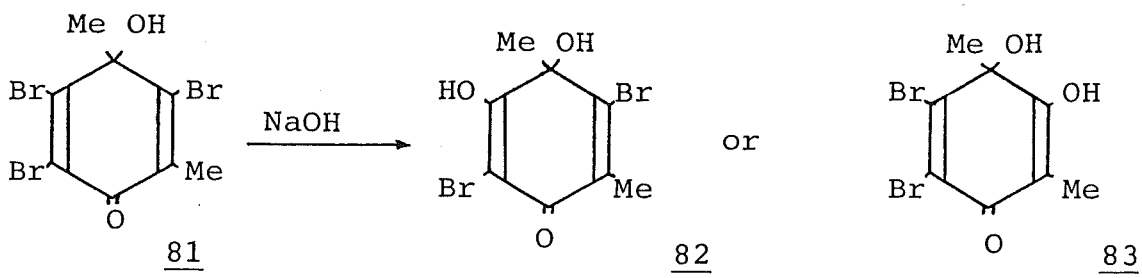


Figure 11

product (78), Scheme 30. This product recrystallised from chloroform as clear crystals of melting point 149-150° with analytical data consistent with a molecular formula of $C_7H_5Cl_3O_3.1H_2O$. The nujol-mull infra-red spectra of the material were similar to those of the tribromo-dihydroxy product (80) with a carbonyl band at 1616 cm^{-1} and carbon-carbon double bonds at 1602 and 1569 cm^{-1}. The solution spectra of this compound (78) were also similar to those of its tribromodihydroxy analog (80), Appendix 5.

The reaction of 3,5,6-tribromo-4-hydroxy-2,4-dimethyldienone (81) with sodium hydroxide is interesting in that there are two possible products that could reasonably be expected depending on whether attack by the hydroxyl group occurs at the C3-or the C5-position. Attack at the C5-position would give the product (82) whereas attack at C3 would give the product (83) below:

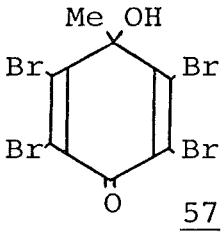


81 82 83

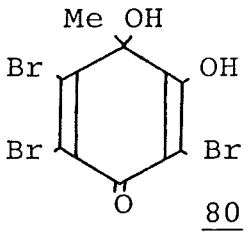
3,5,6-Tribromo-4-hydroxy-2,4-dimethyldienone (81) was treated with 10% aqueous sodium hydroxide solution as for compound (57) above, to give the 3,6-dibromo-4,5-dihydroxy-2,4-dimethylcyclohexa-2,5-dienone (82). Recrystallisation of the crude material from chloroform gave the compound (82) as crystals which decomposed on melting at 191-192°. Analytical data for this product confirmed its $C_8H_8Br_2O_3$ anhydrous molecular formula.

The structure (82) was assigned to the product after consideration of its ^{13}C n.m.r. spectrum when compared to those of compounds (57), (80) and (81), Table 6. Note that in compounds (57), (80) and (81) C2 resonance appears at δ123.5, δ122.6 and δ127.7 respectively (labelled 'a' in Table 6), whereas the C2-resonance in compound (81) appears at δ134.1 (labelled 'b'), Table 6. Analysis of the ^{13}C n.m.r. spectrum of the product resulted in the assignment of the signals at δ134.0 and δ98.9 to the C2 and C6 atoms. The δ98.9 signal corresponded to that expected for a keto-enol system, see compound (80) in Table 6. Indeed this is the structure that would be expected to be more readily formed as the electron-withdrawing bromine atom attached to the adjacent carbon atom (C6) should promote nucleophilic attack at the C5-position compared with the C3-position. No other products

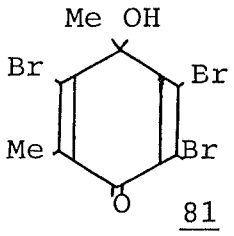
^{13}C n.m.r. Data for Compounds (57), (80), (81) and (82) in CD_3COCD_3.



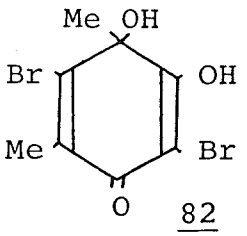
57



80



81



82

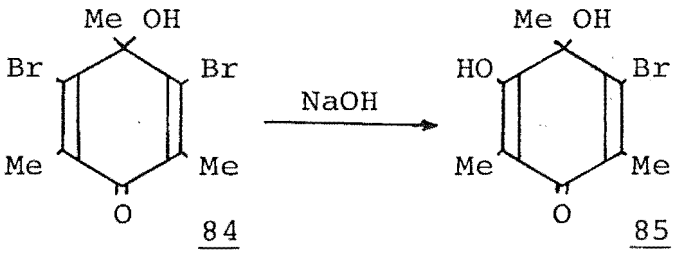
1	167.3	169.3	174.7	177.7
2	123.5[a]	122.6[a]	134.1[b]	134.0
3	152.7	146.2	151.7	146.8
4	75.8	71.8	76.0	74.0
5	152.7	168.2	154.4	172.4
6	123.5[a]	93.0	127.7[a]	98.9

Table 6

were observed.

Although the solution spectra for this compound (82) were similar to those observed in the other dihydroxy compounds above, see Appendix 5, the nujol-mull infra-red spectrum was quite different. The hydroxyl absorption bands appeared at 3250 and 3160 cm^{-1} suggesting increased hydrogen bonding involving the hydroxy groups. For compound (82) other bands observed were a medium band at 1652 cm^{-1} and two strong bands at 1624 and 1608 cm^{-1}. The difference between this infra-red spectrum and those discussed earlier for compounds (78) and (80) must be the result of a completely different hydrogen bonding system in the solid state, when the water molecule of hydration is absent.

Sodium hydroxide treatment of the 3,5-dibromo-4-hydroxy-2,4,6-trimethyldienone (84) as for compound (57), above, gave the dihydroxy product (85):

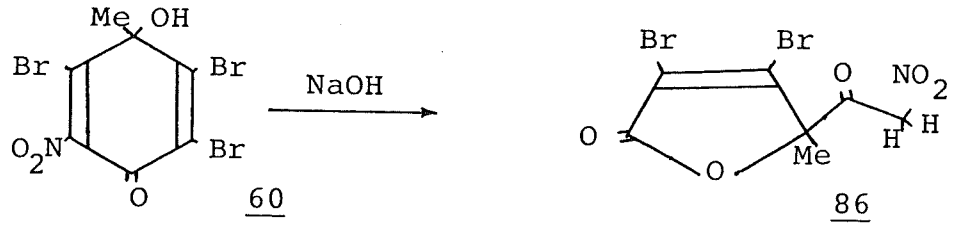


84 85

Recrystallisation of this product (85) from chloroform gave crystals that decomposed on melting at 222-223° and had analytical data consistent with a molecular formula of $C_9H_{11}BrO_3$. The nujol-mull infra-red spectrum of this compound was similar to that of the dihydroxydimethyl compound (82), with a hydroxyl absorption band at 3270 cm^{-1}, and carbonyl and carbon-carbon double bond bands at 1663 (medium), 1620 (medium), 1601 (strong) and 1580 cm^{-1} (medium). Although it was possible to obtain an ultra-violet and a ^1H n.m.r. spectra of this product, both of which fitted the trend observed in the other dihydroxy compounds above, see Apppendix 5, a ^{13}C n.m.r. spectrum was not obtainable due to the low solubility of the product.

In order to determine the effect on the reaction of replacing the bromo group for a more strongly electron-withdrawing nitro group at the α-carbon, the compound 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone(60) was treated with a 10% aqueous solution of sodium hydroxide. Because of the high reactivity of this compound the reaction was carried out over 1 hour at 5°. After acidification of the reaction mixture the 3,4-dibromo-5-methyl-5-(2'-nitroethan-1'-one)-2(5H)-

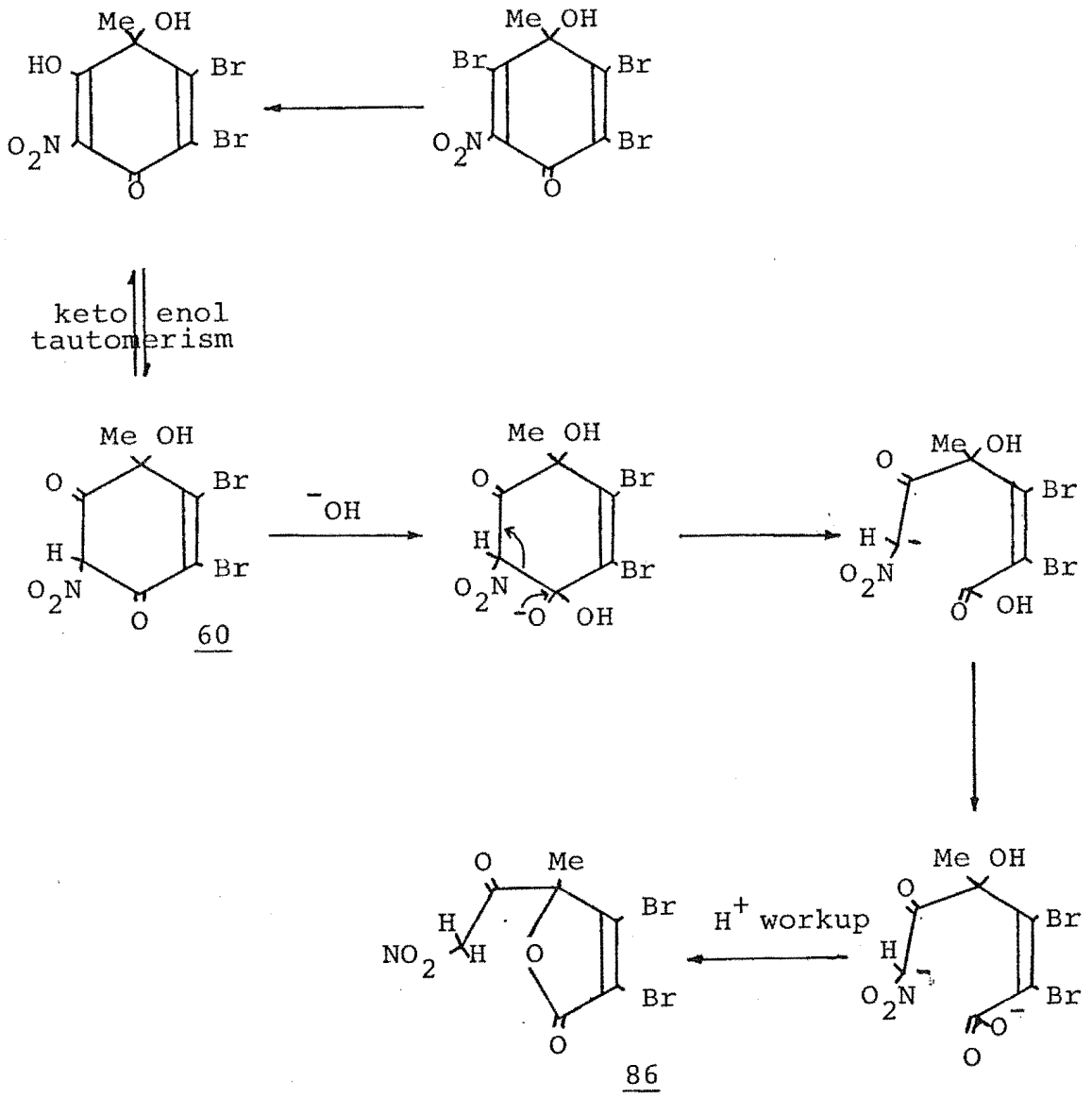
furanone(86)(26%) was isolated:



60 86

The analytical data obtained on this product was in agreement with the $C_7H_5Br_2NO_5$ structure (86) assigned on the basis of a single-crystal X-ray analysis carried out on the compound, details of which can be seen in Appendix 4. The infra-red spectra contained the high frequency lactone carbonyl absorption band at 1778 cm^{-1} and a saturated ketone band at 1744 cm^{-1}. The ^{13}C n.m.r. spectrum of the furanone (86) was similar to that of the furanone (52), discussed earlier, and is shown on pages 117 to 118.

A possible mode of formation of furanone (86) is given in Scheme 31. In this scheme the intermediate (60) in its diketo form reacts with base at C1 followed by ring-opening. This ring-opening is presumably promoted by the strong electron-withdrawing nitro group. The lactone ring system then arises on acidification of the reaction mixture.


Me OH
HO
Br
Br
O_2N
O
keto enol tautomerism
^-OH
H
60
H^+ workup
NO_2
86

Scheme 31

CHAPTER VI

REARRANGEMENT OF THE 4-METHYL-4-NITROCYCLOHEXA-2,5-DIENONES

Rearrangement of 4-Nitrodienones in (D)-Chloroform: Our interest in the rearrangement of the 4-nitrocyclohexa-2,5-dienones of the type discussed in the introduction, pages 20 to 22, began when the ^{1}H n.m.r. spectrum of the 2,3,5,6-tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in (D)-chloroform solution was obtained. The solution was observed to turn an orange colour, then red. A series of ^{1}H n.m.r. spectra of the solution were run over several hours and a graph of the results prepared, Figure 12. After leaving the solution for another 2 days, the δ1.98

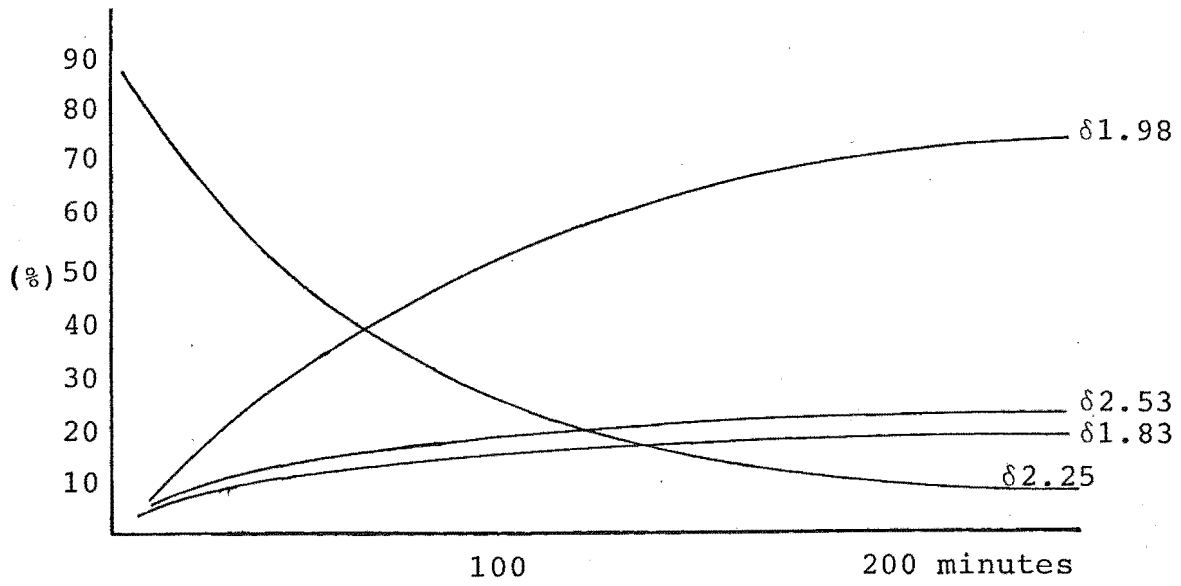


Figure 12

signal had been replaced by a signal at δ1.83. At this stage the mixture was separated into its components. The compounds corresponding to the signals at δ1.83 and δ2.53 were found to be the tetrachloro-4-hydroxy-4-methyldienone (77) and the 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) respectively. Both compounds were identified from their spectroscopic data and by comparison with authentic samples.

In order to determine the effect of a radical scavanger on the rearrangement, two solutions of the tetrachloro-4-nitrodienone (87) dissolved in (D)-chloroform were prepared. To one was added 1,4-hydroquinone. This solution was stored in the dark at 30° for 2 days. The control solution was stored for 4.5 days. Workup for both solutions involved the removal of the solvent and the separation of the crude product on a silica gel Chromatotron plate to give the products shown in Table 8. Compounds (77), (89) and (90) were identified by comparison of their

Products from the Rearrangement of Compound (87) in $CDCl_3$

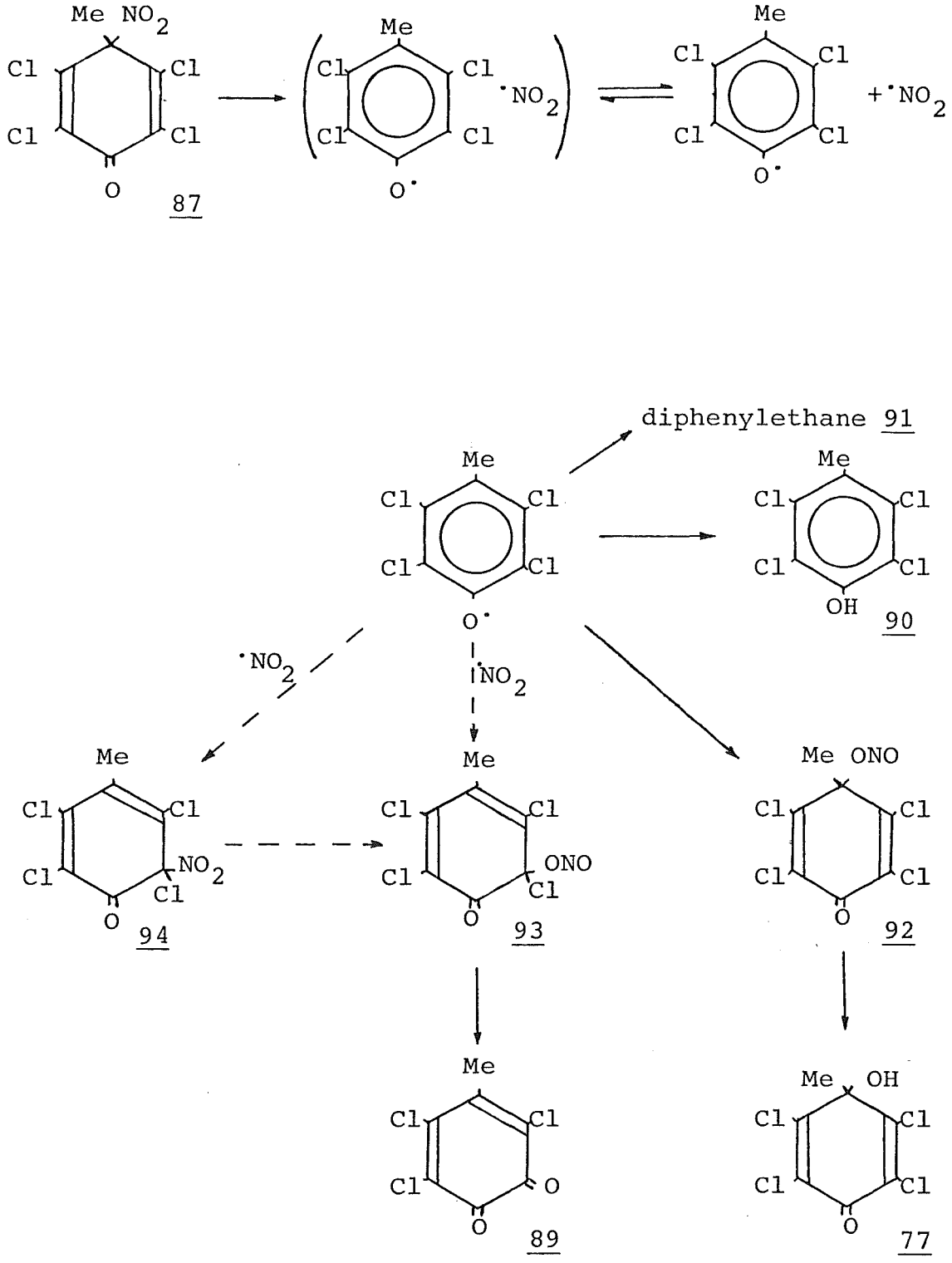
	With Hydroquinone	Without Hydroquinone
tetrachloro-4-methylphenol (90)	56%	-
trichloro-1,2-benzoquinone (89)	-	33%
tetrachloro-4-hydroxydienone (77)	17%	56%
diphenylethane (91)	2.4%	-
Accountability	76%	89%

Table 8

spectroscopic data with those of authentic samples. A further compound (91) was isolated from the rearrangement mixture containing the hydroquinone and was tentatively assigned the structure 1,2-di(2',3',5',6'-tetrachloro-4'-hydroxyphenyl)ethane (91). This white powder decomposed on melting at 176°-178° and had an infra-red spectrum similar to that of the tetrachlorophenol (90).

The mechanism proposed for this rearrangement is shown in Scheme 32. The tetrachlorophenol (90) was formed by abstraction of the hydrogen atom by the phenoxy radical after the nitrogen dioxide had been removed from the solution by the 1,4-hydroquinone, and the diphenylethane (91) was formed by the coupling of two phenoxy radicals. Formation of the 4-hydroxydienone (77) is envisaged as occurring *via* the 4-nitritodienone (92), itself formed by recombination of the radical pair. The 1,2-benzoquinone (89) is probably formed from the 6-nitritodienone (93), by loss of NOCl. It is unclear whether the 6-nitritodienone (93) is formed by direct recombination of the radical pair or by initial formation of the 6-nitrodienone (94) from the radical pair, followed by rearrangement. Note that in order for the 1,4-hydroquinone to capture the nitrogen dioxide it was necessary for the nitrogen dioxide to leave the solvent cage. Clearly, the rearrangement should not be thought of only as an extramolecular rearrangement, but as a dissociation followed by an intermolecular recombination with the possibility of little or no extramolecular rearrangement.

Although the 4-nitritodienone (92) was relatively stable in solution and was observed to hydrolyse slowly over

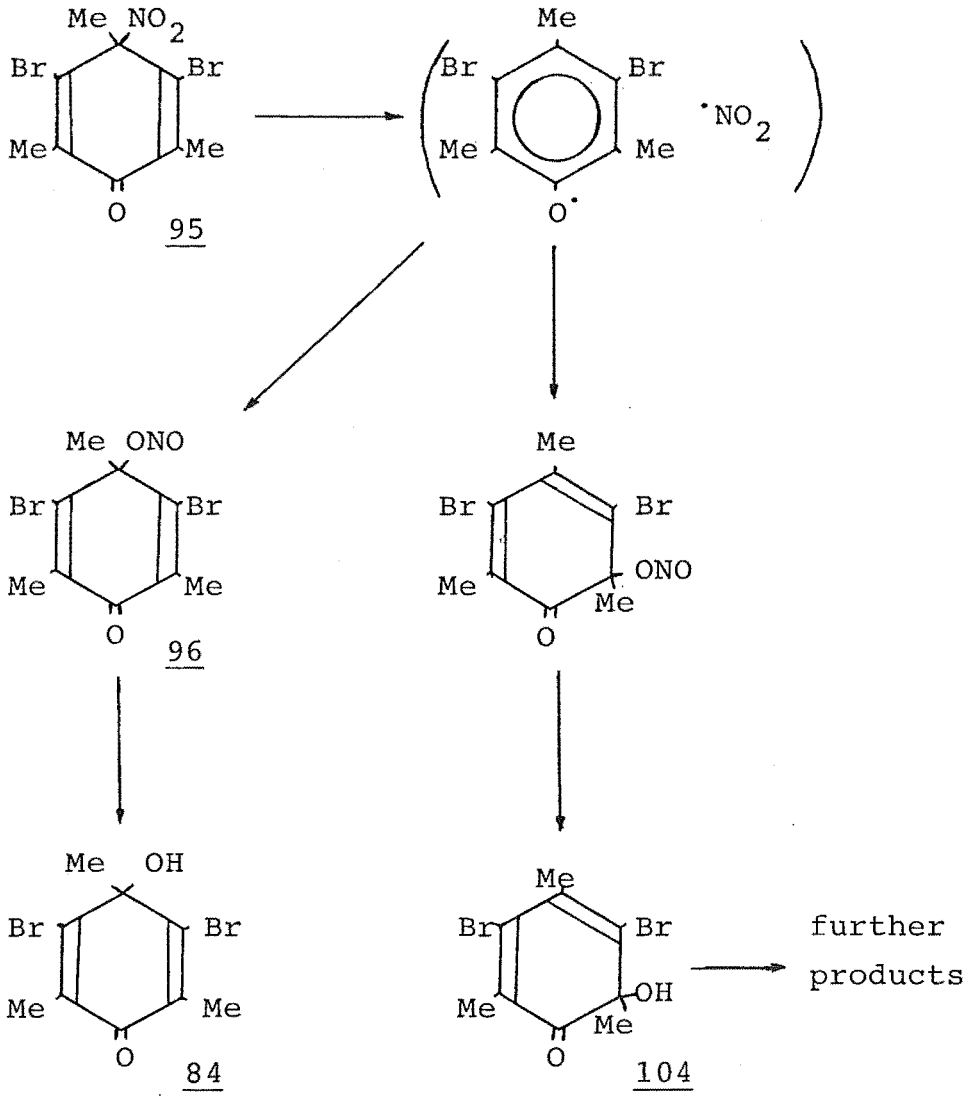

Me NO2
Cl
Cl
Cl
Cl
O
87
Me
Cl
Cl
Cl
Cl
O·
·NO2
Me
Cl
Cl
Cl
Cl
O·
+·NO2
diphenylethane 91
Me
Cl
Cl
Cl
Cl
O·
Me
Cl
Cl
Cl
Cl
OH
90
·NO2
·NO2
Me
Cl
Cl
Cl
NO2
Cl
O
94
Me
Cl
Cl
Cl
ONO
Cl
O
93
Me ONO
Cl
Cl
Cl
Cl
O
92
Me
Cl
Cl
Cl
O
O
89
Me
OH
Cl
Cl
Cl
Cl
O
77

Scheme 32

2 days to give a 4-hydroxydienone (77), attempts to isolate it were unsuccessful. However, it was possible to obtain a ^{13}C n.m.r. spectrum of the 4-nitritodienone intermediate (92) when it was present as 63% of the total product in solution. This spectrum was similar to that observed for the tetrachloro-4-hydroxydienone (77) and was in accord with the structure (92); ^{13}C n.m.r. ($CDCl_3$,-25°) δ 25.9, CH_3; 80.7, C4; 131.2, C2/C6; 151.9, C3/C5; 169.8, C1.

In comparison with the rearrangement of the tetrachloro-4-nitrodienone (87), the rearrangement of the 3,5-dibromo-2,4,6-trimethyl-4-nitrodienone (95) in (D)-chloroform proceeded slowly with a half-life of approximately 21 hours. (The half-life of the tetrachloro-4-nitrodienone (87) was approximately 45 minutes.) After storing the dibromotrimethylnitrodienone (95) in (D)-chloroform for 4 days some starting material (95) (22%) was recovered in addition to the corresponding 4-hydroxydienone (84) (64%). This compound (84) was identified by comparison of its spectroscopic data with that of an authentic sample. Formation of the 4-hydroxydienone (84) presumably proceeds *via* the 4-nitrite ester (96), Scheme 33.

Rearrangement of 4-Nitrodienones in Benzene: In order to determine the effect of the solvent on the rearrangements of the 4-methyl-4-nitrocyclohexa-2,5-dienones, it was decided that the above reactions should be repeated using a range of solvents. In dry benzene solution the tetrachloro-4-nitrodienone (87) was observed to rearrange at a similar rate to that in (D)-chloroform, and after 14 days, separation of the components of the reaction mixture

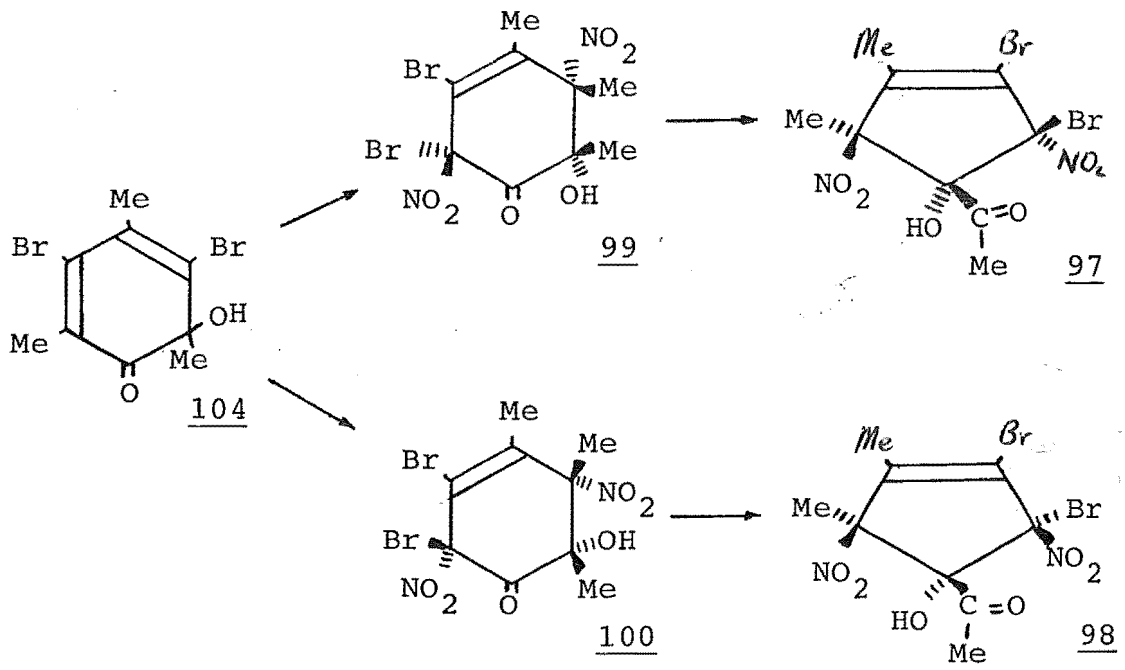


Scheme 33

gave the trichloro-1,2-benzoquinone (89)(57%) and the tetrachloro-4-hydroxydienone (77)(26%). The rearrangement presumably occurs by the mechanism above, Scheme 32. In the present case the yield of 1,2-benzoquinone (89) was higher at the expense of the 4-hydroxydienone (77). This presumably reflects the greater ability of benzene as compared with (D)-chloroform to sustain 6-nitritodienone (93) formation rather than that of 4-nitritodienone (92).

Rearrangement of the dibromotrimethyl-4-nitrodienone (95) in dry benzene for 36 hours gave the trimethyl-4-hydroxydienone (84)(67%) and the isomeric dinitrocyclopent-3-en-1-ols (97)(11%) and (98)(3%). These compounds (97) and

(98) were identified by comparison of their spectroscopic data with those reported by Hartshorn *et al.*[37]. It appears that the two cyclopentenols (97) and (98) are formed from the intermediate 6-hydroxy-2,5-dinitrocyclohexa-3-enones (99) and (100) respectively during the chromatographic separation of the reaction mixture. Such acyloin rearrangements have been demonstrated for 6-hydroxy-2,5-dinitrocyclohexa-3-enones with structures similar to compounds (99) and (100)[38]. These 6-hydroxy-2,5-dinitrocyclohex-3-enones (99) and (100) are believed to be formed by the addition of free nitrogen dioxide to the 6-hydroxydienone (104) presumed to be present in the reaction media, Schemes 33 and 34.

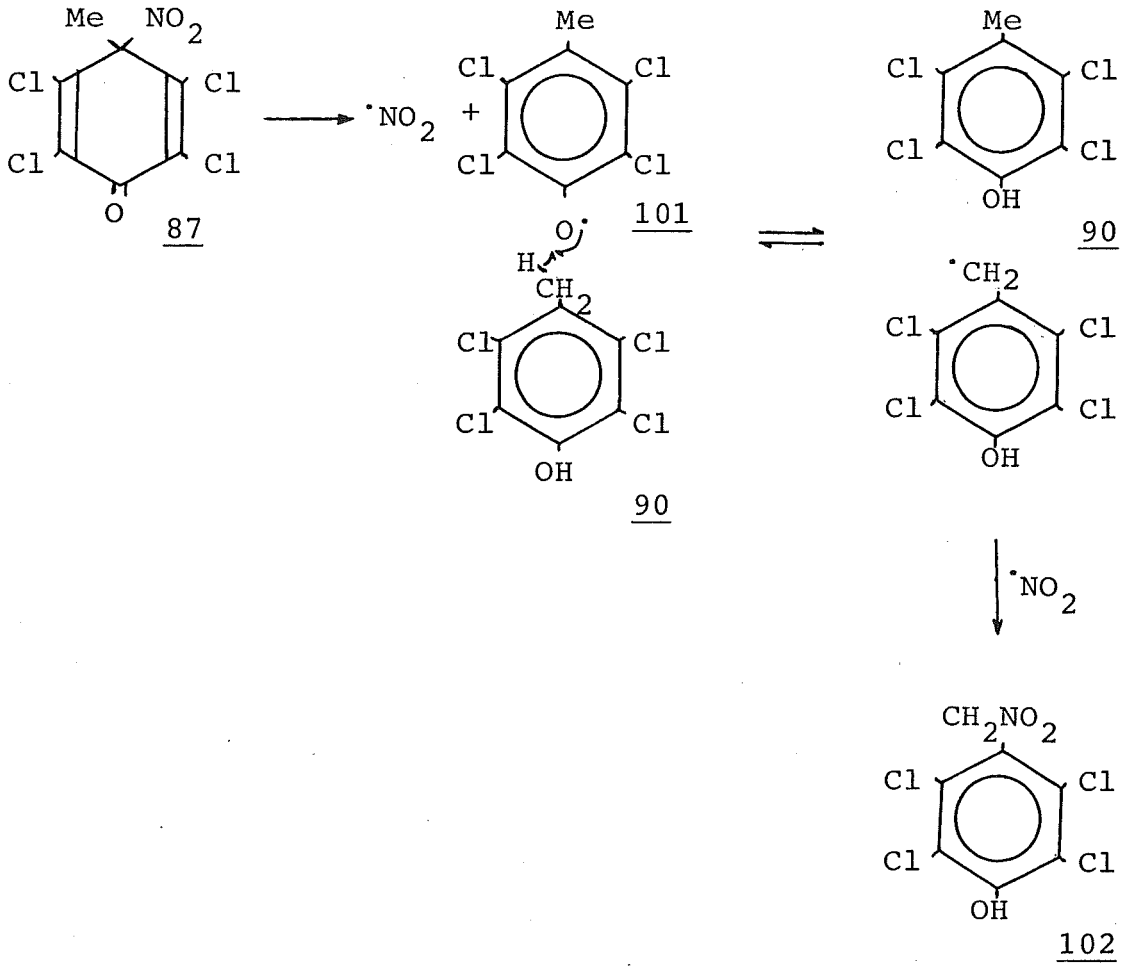


Scheme 34

From the increased yield of products resulting from a 1,3-nitro shift compared to that of 4-hydroxydienone (84), a change in the solvent from (D)-chloroform to benzene appears to have a similar effect on the course of the rearrangement of the dibromonitrodienone (95) as that reported above for the tetrachloronitrodienone (87).

Rearrangement of Tetrachloronitrodienone (87) in Benzene in the Presence of Tetrachlorophenol (90): Equimolar amounts of the tetrachloro-4-nitrodienone (87) and the corresponding tetrachlorophenol (90) were dissolved in dry benzene and stored for 58 hours. Workup and separation of the resulting mixture gave the tetrachlorophenol (90) (31%), the tetrachloro-4-hydroxydienone (77)(13%), the trichloro-1,2-benzoquinone (89)(3%) and the 2,3,5,6-tetrachloro-4-(nitromethyl)phenol (102)(33%).

The side-chain-nitro phenol (102) was identified as a phenol containing a nitro group by its infrared spectrum, and found to contain a $-CH_2-Ar$ group as opposed to a methyl group (^1H n.m.r. spectrum). ^{13}C n.m.r. and

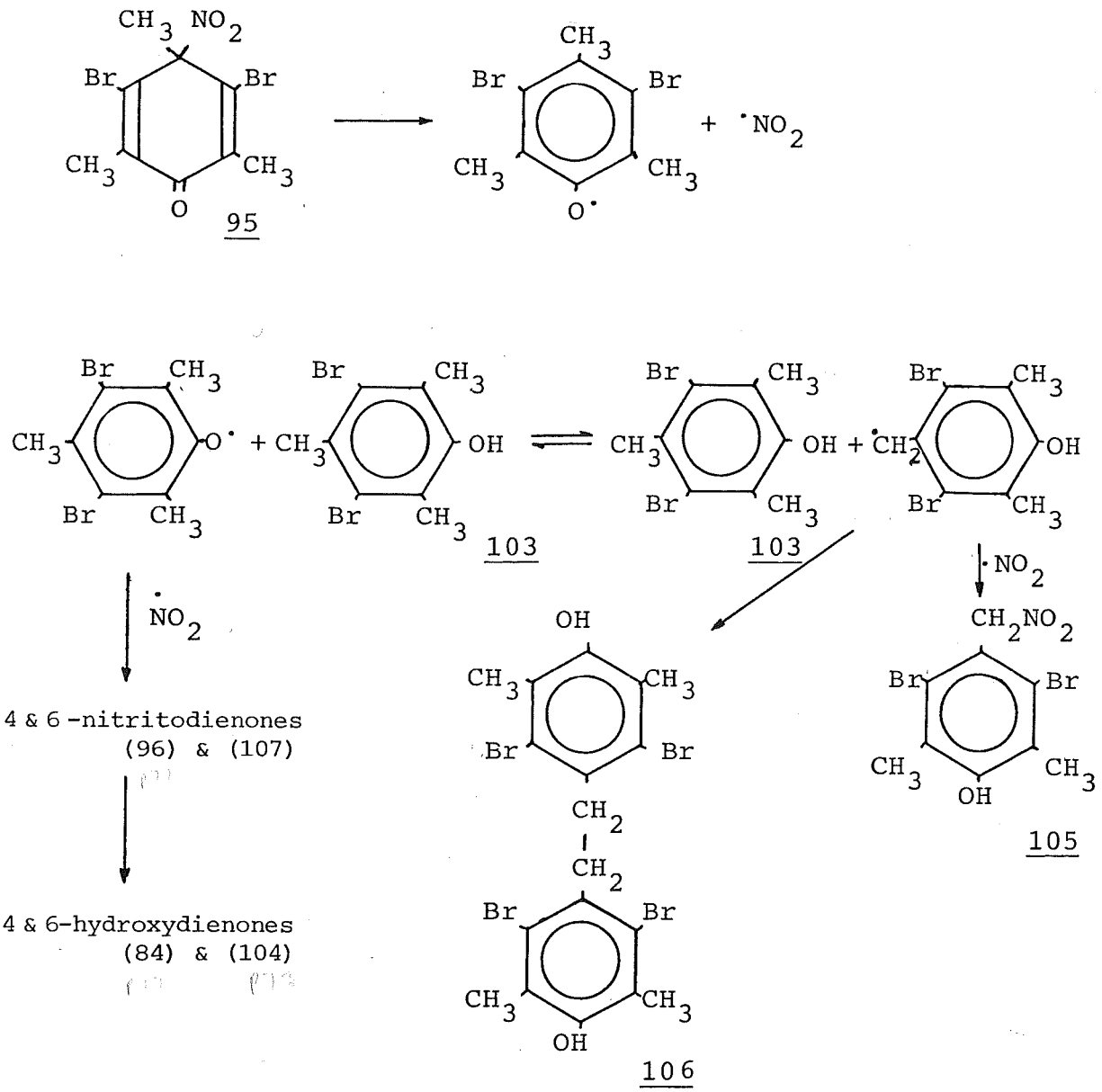


Scheme 35

analytical data were consistent with the assigned structure (102). The mechanism proposed for the formation of this produce is shown in Scheme 35. In this reaction scheme a hydrogen atom is abstracted from the methyl group of the phenol (90) by the phenoxy radical (101) resulting in the formation of a benzylic radical which combines with nitrogen dioxide to form the product (102).

Rearrangement of Dibromotrimethylnitrodienone (95) in Benzene in the Presence of Dibromotrimethylphenol (103): The rearrangement of equimolar amounts of dibromotrimethyl-4-nitrodienone (95) and the corresponding dibromotrimethylphenol (103) in dry benzene over 50 hours yielded the dibromotrimethylphenol (103)(34%), the dibromotrimethyl-6-hydroxydienone (104)(10%), the dibromotrimethyl-4-hydroxydienone (84)(4%), the 3,5-dibromo-2,6-dimethyl-4-(nitromethyl) phenol (105)(33%) and the 1,2-di(2',6'-dibromo-4'-hydroxy-3',5'-dimethylphenyl)ethane (106)(4%).

The dibromo side-chain-nitro phenol (105) was identified in a similar manner to the earlier side-chain-nitro phenol (102); the molecular formula being confirmed by its analytical data. The diphenylethane (106) had an infra-red spectrum consistent with that of a phenolic compound and the ^{1}H n.m.r. spectrum was in accord with the assigned structure (106) as was its analytical data. From observation of the melting point, solubility, high retention on silicagel and general appearance of the crystals, this compound was found to fit the pattern observed for the substituted diphenylethanes discussed earlier. The proposed mechanism for the formation of this product is outlined in Scheme 36. When



Scheme 36

this arrangement was repeated in (D)-chloroform, separation of the resulting mixture gave the dibromotrimethylphenol (103)(21%), the dibromotrimethyl-6-hydroxydienone (104)(16%), the dibromotrimethyl-4-hydroxydienone (84)(4%), the dibromo (nitromethyl)phenol (105)(25%) and the diphenylethane (106) (4.5%).

It should be noted that in each of the three rearrangements discussed above that involve the addition of a phenol to the reaction mixtures, reaction occurred more rapidly with a half-life to the formation of *stable* products in the order of 1 to 3 hours.

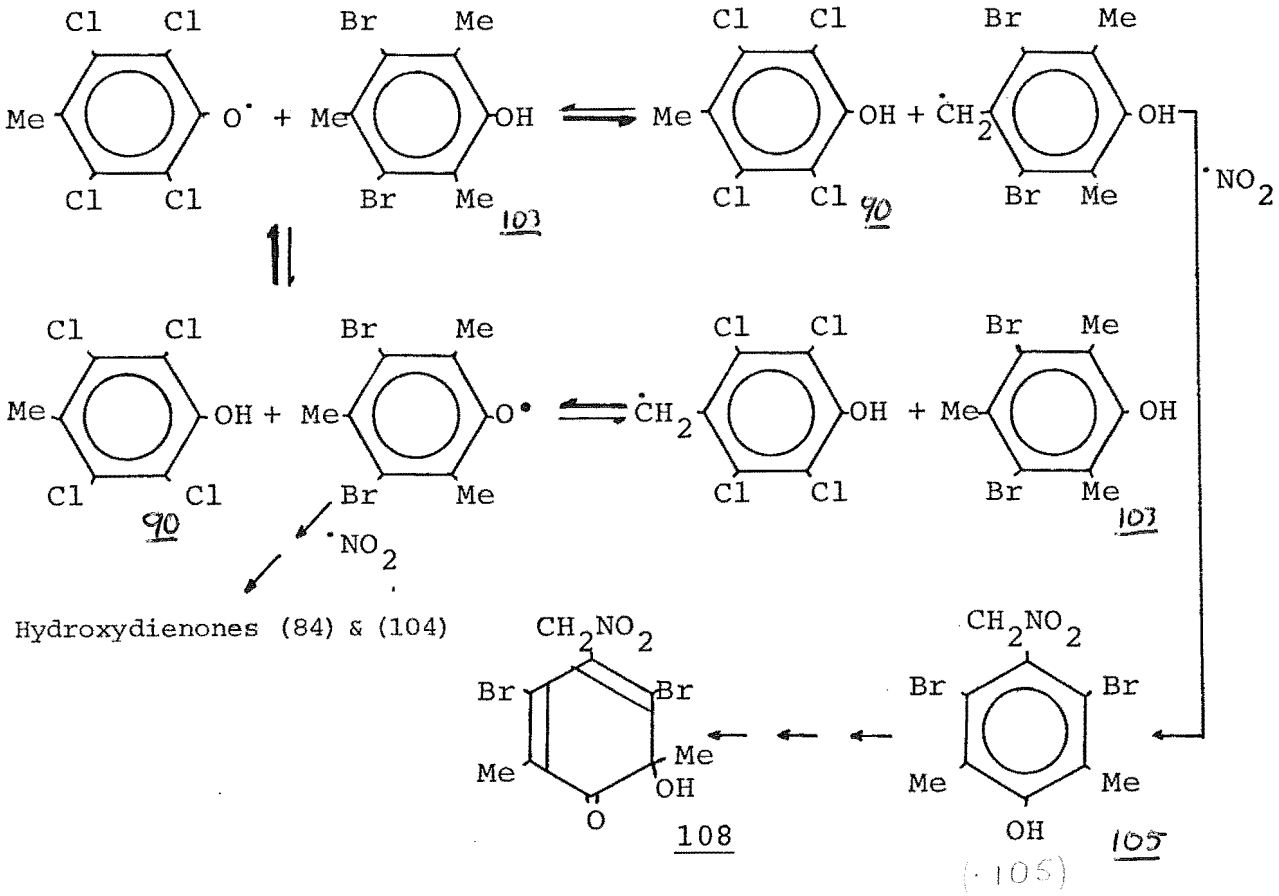
Rearrangement of Tetrachloronitrodienone (87) in Benzene in the Presence of 3,5-Dibromo-2,4,6-trimethylphenol (103): The (nitromethyl)phenols (102) and (105) and the diphenylethane (106) were only obtained in the rearrangements above on the addition of their corresponding phenols (90) or (103), to the rearrangement mixture. In order to provide further evidence in support of the proposed mechanism for these reactions, Scheme 35 and 36, cross-over reactions were performed involving the rearrangements of the nitrodienones (87) and (95) in the presence of the non-common phenols (103) and (90) respectively.

Rearrangement of the tetrachloronitrodienone (87) dissolved in dry benzene containing an equimolar amount of the dibromotrimethylphenol (103) over 50 hours gave the tetrachlorophenol (90) (41%), the tetrachloro(nitromethyl)-phenol (102) (1%), and the bromo-products dibromotrimethyl-6-hydroxydienone (104) (5%), dibromotrimethyl-4-hydroxy-dienone (84) (5%), dibromo(nitromethyl)phenol (105) (18%) and further material believed to be the 3,5-dibromo-6-hydroxy-2,6-dimethyl-4-(nitromethyl)cyclohexa-2,4-dienone (108) (9%). Unfortunately the latter compound (108) was unstable and pure material could not be obtained. The tentative structure assignment is based on the infra-red and ^{1}H n.m.r. spectra

of this material. The mechanism proposed for this rearrangement is discussed below.

Rearrangement of Dibromotrimethylnitrodienone (95) in Benzene in the Presence of Tetrachlorophenol (90):

The dibromotrimethyl-4-nitrodienone (95) was dissolved in dry benzene containing an equimolar amount of the tetrachlorophenol (90) and was stored for 50 hours. The resulting mixture was found to contain the tetrachlorophenol (90) (43%), the dibromotrimethyl-6-hydroxydienone (104) (4%), the dibromotrimethyl-4-hydroxydienone (84) (8%), the



Scheme 37

dibromo(nitromethyl)phenol (105)(22%) and the 3,5-dibromo-6-hydroxy-2,6-dimethyl-4-(nitromethyl)cyclohexa-2,4-dienone (108)(4%).

The product composition for this rearrangement is similar to that for the rearrangement of the tetrachloro-nitrodienone (87) in the presence of the dibromotrimethyl-phenol (103) discussed above. It appears likely that these two reactions proceed by the common intermediate system shown in Scheme 37.

Additional 4-Nitrodienone Rearrangements: Rearrangement of the 3,5,6-tribromo-2,4-dimethyl-4-nitrodienone (109) in (D)-chloroform was carried out over four days to give the 3,5,6-tribromo-2,4-dimethyl-4-nitratodienone (110)(6%), the corresponding 4-hydroxydienone (81)(65%) and the 3,5-dibromo-4,6-dimethyl-1,2-benzoquinone (111)(c.4%).

The 4-nitratodienone (110) was identified from its characteristic organic nitrate infra-red absorptions at 1650, 1280 and 835 cm^{-1}. Analytical data for the organic nitrate (110) was in accord with the molecular formula $C_8H_6Br_3NO_4$. The 4-hydroxydienone (81) was identified by comparison of its spectroscopic data with that of an authentic sample, and the 1,2-benzoquinone (111) recrystallised from dichloromethane-petroleum ether as bright red needles with an infra-red spectrum exhibiting two carbonyl absorptions at 1695 and 1657 cm^{-1}. The ^1H n.m.r. and ultra-violet spectra of this compound (111) were also consistent with the assigned structure, and analytical data for the compound were in accord with the molecular formula $C_8H_6Br_2O_2$.

The mode of formation of the 4-hydroxydienone (81) and the 1,2-benzoquinone (111) is expected to be similar to that of the analogous compounds (77) and (89), Scheme 32. The nitratodienone (110) appears to be formed by an esterification reaction of 4-hydroxydienone (81) in solution by small amounts of nitronium ion formed during the rearrangement.

Rearrangement of the tetrachloro-4-nitrodienone (87) dissolved in CD_3CO_2D was studied by following the ^1H n.m.r. spectrum of the solution, the results of which are shown in Figure 13. Note that the rate of rearrangement was not

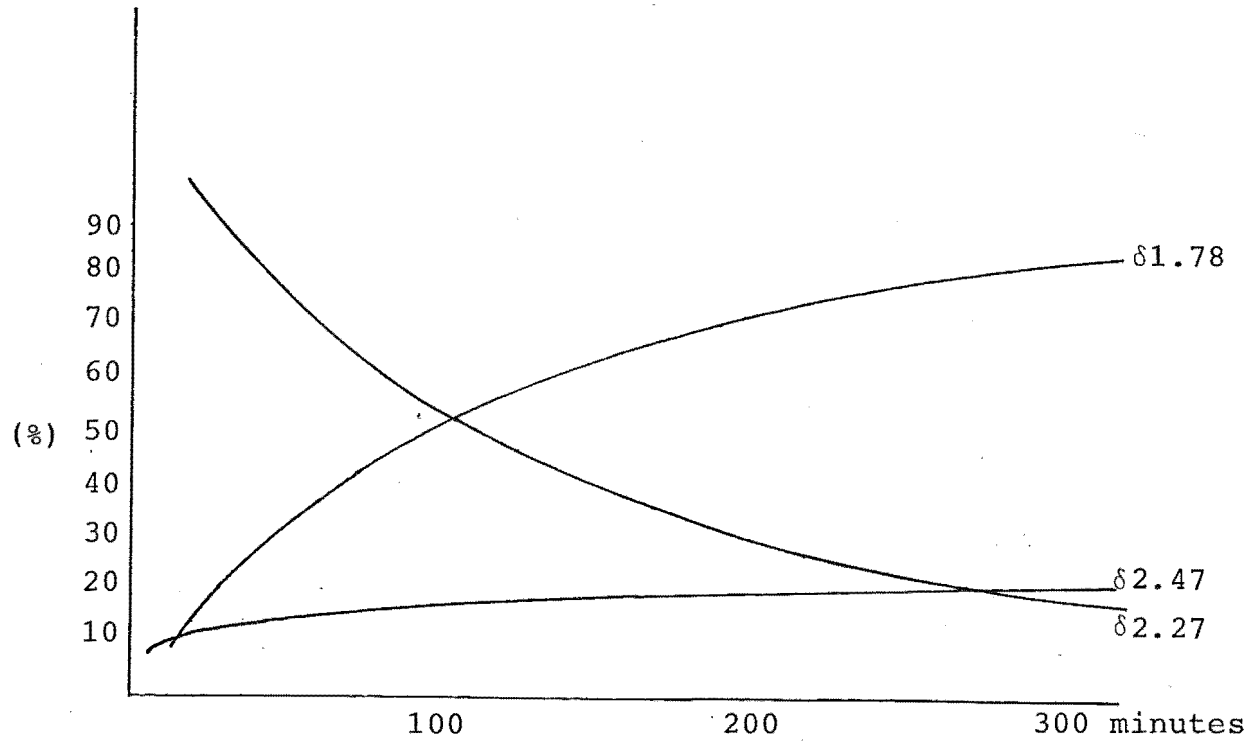


Figure 13

significantly different to that in (D)-chloroform, but with CD_3CO_2D no intermediate compounds were observed. The products isolated from the reaction mixture proved to be the tetrachloro-4-hydroxydienone (77) and the trichloro-1,2-benzoquinone (89).

In order to determine the effect of adding a radical scavanger to this rearrangement mixture, two solutions of the tetrachloro-4-nitrodienone (87) dissolved in analytical grade acetic acid were prepared. To one was added 1,4-hydroquinone. Both solutions were stored in the dark at 30° for 1 day before being separated on a silica gel Chromatotron plate. The products obtained are recorded in Table 9. Note that the product distribution is similar to that obtained when (D)-chloroform was used as the solvent, Table 8.

Products from the Rearrangement of Compound (87) in Acetic Acid

	With Hydroquinone	Without Hydroquinone
Tetrachloro-4-methylphenol (90)	38%	0.8%
Trichloro-1,2-benzoquinone (89)	4%	19%
Tetrachloro-4-hydroxydienone (77)	24%	76%
Accountability	66%	96%

Table 9

The rearrangement of the tetrabromo-4-methyl-4-nitrocyclohexa-2,5-dienone (112) in acetic acid containing sodium acetate was also investigated. The suspension was stirred at 20° for 7 days in the dark before the components of the

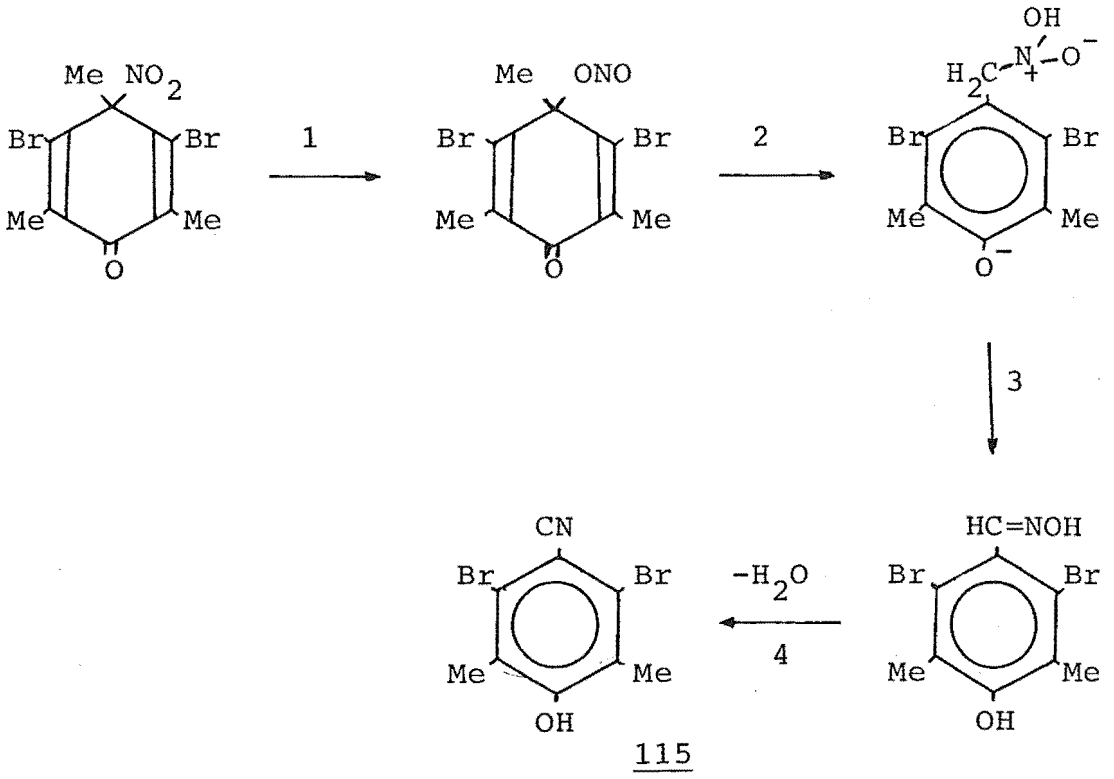
mixture were separated to give the tetrabromo-4-methylphenol (55)(96%), the 2,3,5-tribromo-4-methyl-6-nitrophenol (58) (2%) and the tetrabromo-4-hydroxydienone (57) (2%). All three products were identified by comparison of their spectroscopic data with those of authentic samples. When the rearrangement was repeated using an aqueous acetic acid-acetate buffer system as the solvent, no reaction occurred and the starting material was recovered.

Rearrangement of the tribromo-2,4-dimethyl-4-nitrodienone (109) in acetic acid containing sodium acetate gave the 2,3,5-tribromo-6-hydroxy-4,6-dimethylcyclohexa-2,4-dienone (116)(33%) and the tribromo-4-hydroxydienone (81)(15%). The remaining material consisted of a complex mixture of polar oils. The 6-hydroxydienone (116) was recognised as a cyclohexa-2,4-dienone from its ultra-violet spectra and from the strong carbon-carbon double bond infra-red absorption at 1610 cm^{-1}, see trends in Appendix 5. The ^{1}H n.m.r. and analytical data for the compound were in agreement with the assigned structure (116). When the rearrangement was repeated in an aqueous acetic-acetate buffer system no reaction was observed and over 93% of the starting material was recovered.

Rearrangement of the dibromotrimethyl-4-nitrodienone (95) in acetic acid containing sodium acetate gave the dibromotrimethyl-6-hydroxydienone (100)(80%), the 4-hydroxy-dienone (84)(8%) and the 4-acetoxymethyl-3,5-dibromo-6-hydroxy-2,6-dimetnylcyclohexa-2,4-dienone (113)(7%). This last product (113) was identified from its infra-red, ultra-violet and ^{1}H n.m.r. spectra. Analytical data and low resolution mass spectroscopy confirmed the $C_{11}H_{12}Br_2O_4$

molecular formula. It is interesting to note the high proportion of 6-hydroxycyclohexa-2,4-dienone obtained in these rearrangements when sodium acetate is present.

When the dibromotrimethyl-4-nitrodienone (95) was suspended in an aqueous acetic acid-acetate buffer system for 7 days, the products were the 2-acetoxymethyl-3,5-dibromo-4,6-dimethylphenol (114)(3%), the 6-hydroxydienone (104)(35%), the 4-hydroxydienone (84)(17%), the dibromodimethyl-4-(nitromethyl)phenol (105)(19%) and the 3,5-dibromo-4-cyano-2,6-dimethylphenol (115)(26%). The mechanism leading to the formation of the cyano compound (115) would appear to proceed by a rearrangement process similar to that shown below:



115

Rearrangement of the type shown in steps 3 and 4 have been reported previously[57,58].

CHAPTER VII

BROMINATION-DE-NITRATION OF 2,4-DIMETHYL-6-NITROPHENOL

INTRODUCTION

As discussed in the general introduction, Chapter 1, *ipso* displacements have been observed to occur. The leaving ability of the ipso substituents is in the order $Cl<NO_2<Br<I$.[21a] Therefore nitro-de-brominations could be expected to occur readily and bromination-de-nitrations could be expected to occur less easily. Bromination-de-nitrations have been reported however[59].

DISCUSSION

Prior to the successful preparation of the 3,5-dibromo-2,4-dimethyl-6-nitrophenol by treating the 2,3,5-tribromo-4,6-dimethylphenol with sodium nitrite, attempts were made to prepare the dibromodimethylnitrophenol by bromination of 2,4-dimethyl-6-nitrophenol (28c) in chloroform using molecular bromine and iron dust as a catalyst. Separation of the resulting mixture by silica gel dry column chromotography and by silica gel Chromatotron plate gave the starting phenol (28c)(68%), the 3-bromo-2,4-dimethyl-6-nitrophenol (23%) and the 2,3,5-tribromo-4,6-dimethylphenol (12%).

Formation of the tribromodimethylphenol is the result of a bromination-de-nitration substitution reaction.

CHAPTER VIII

EXPERIMENTAL METHODS

Infrared spectra were recorded on a Shimadzu IR-27G spectrophotometer for liquid films and nujol mulls. Ultraviolet absorption spectra were determined for chloroform and dioxan solutions on Varian Superscan 3 or Varian DMS 100 spectrophotometers.

Routine ^{1}H n.m.r. spectra were obtained for deuteriochloroform and deuterioacetone solutions, with tetramethylsilane as an internal reference on a Varian T60 spectrometer. ^{1}H n.m.r. and ^{13}C n.m.r. Fourier Transform spectra were recorded on a Varian CFT-20 Fourier Transform NMR spectrometer for deuteriochloroform and deuterioacetone solutions with tetramethylsilane as an internal reference. All chemical shifts are expressed as parts per million (ppm) downfield from TMS and are quoted as position (δ), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), relative integral and coupling constants (J, Hz).

Microanalyses were carried out by Professor A.D. Campbell and associates, University of Otago.

Melting points were determined in open capillaries and are uncorrected.

Preparative scale chromatography was routinely carried out utilising a Chromatotron (a preparative, centrifugally accelerated, radial, thin-layer chromatograph. Model 7924, Harrison Research Inc.) equipped with rotors coated with silica gel PF-254 (with $CaSO_4.\frac{1}{2}H_2O$ type 60 for TLC, Merck : E.M. Laboratories Inc., item number 7749) of various thicknesses

(generally 2 mm).

All solvents used were either of analytical grade (AR) or were purified and dried according to standard procedures. "Ether" refers to commercial diethylether distilled off phosphorus pentoxide, and "Petroleum ether (Pet. ether)" refers to petroleum ether (50-70 °C) distilled off phosphorus pentoxide.

2-Chloro-4-methyl-6-nitrophenol (28a)

2-Chloro-4-methyl-6-nitrophenol (28a) was prepared by chlorination of 4-methylphenol dissolved in chloroform using sulphuryl chloride, followed by nitration of the chlorinated phenol dissolved in acetic acid using nitric acid (d 1.5). The crude product was purified by silica gel column chromatography and recrystallisation from pet. ether as yellow crystals of m.p. 62-63° (lit. m.p. 65°)[25]. ν_{max} (Nujol) 3220 (OH); 1622 (phenyl); 1550 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.35, s, CH_3; 7.52, m, J2 Hz, H3; 7.85, m, J2 Hz, H5; 10.85, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 20.0, CH_3; 124.1, C2, C5; 130.9, C4; 135.2, C6; 138.8, C3; 149.4, C1.

2-Bromo-4-methyl-6-nitrophenol (28b)

2-Bromo-4-methyl-6-nitrophenol (28b) was prepared by bromination of 4-methylphenol dissolved in chloroform using bromine, followed by nitration of the bromophenol dissolved in acetic acid using nitric acid (d 1.5). The crude product was purified by silica gel column chromatography and recrystallised from pet. ether as yellow crystals of m.p. 65-66.5° (lit. 68°)[39]. ν_{max} (Nujol) 3160 (OH); 1620 (phenyl); 1543 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.33, s, CH_3; 7.58, m, J2 Hz, H3; 7.77, m, J2 Hz, H5; 10.96, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 19.9, CH_3; 113.1, C2; 124.9, C5; 131.7, C4; 135.0, C6; 142.1, C3; 150.3, C1.

Nitration of 2-Chloro-4-methyl-6-nitrophenol (28a)

The phenol (28a) (1 g) was added over 30 min. to fuming nitric acid (4.5 ml; d 1.5), which was stirred at 50-55°, and the resulting solution kept at 50-55° for 5 min. The solution was then cooled, water added dropwise and the crystalline 5-chloro-2-methyl-3-nitro-1,4-benzoquinone (29a) (511 mg) collected by filtration. Extraction of the aqueous filtrate with chloroform gave an oil (93 mg), which yielded further quinone (29a) (47 mg) and polar oily fractions when separated on a silica gel Chromatotron plate; the polar oily fractions were shown (t.l.c., infrared, ^{1}H n.m.r. spectra) to be complex mixtures. 5-Chloro-2-methyl-3-nitro-1,4-benzoquinone (29a) (yield 52%), recrystallised from carbon tetrachloride, had m.p. 125-126° (lit. m.p. 128°)[25]. ν_{max} (Nujol) 1692, 1672 (C=O); 1601 (C=C); 1554, 1537 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 2.13, s, CH_3; 7.17, H6; ^{13}C n.m.r. (CD_3COCD_3) δ 11.5, CH_3; 135.4, C6; 137.5, C2, 142.4, C5; 171.8, C4; 183.8, C1; signal for C-NO_2 not detected. λ_{max} ($CHCl_3$) 271 nm (ε 8,500).

Nitration of 2-Bromo-4-methyl-6-nitrophenol (28b)

The phenol (28b) (1 g) was added over 10 min. to stirred fuming nitric acid at 50-55°, and the resulting solution was stirred for a further 5 min. The solution was then cooled, water added dropwise, and the crystalline 5-bromo-2-methyl-3-nitro-1,4-benzoquinone (29b) (601 mg) collected by filtration. Extraction of the aqueous filtrate

with chloroform gave a residue (164 mg), which yielded further quinone (29b) (63 mg) and polar oily fractions when separated on a silica gel Chromatotron plate; the polar oily fractions were shown (t.l.c., infrared, ^{1}H n.m.r. spectra) to be complex mixtures. 5-Bromo-2-methyl-3-nitro-1,4-benzoquinone (29b) (yield 63%), recrystallised from chloroform - carbon tetrachloride, had m.p. 135-137° (lit. m.p. 135°)[26]. ν_{max} (Nujol) 1689, 1667 (C=O); 1600 (C=C); 1540 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 2.13, s, CH_3; 7.43, H6; ^{13}C n.m.r. (CD_3COCD_3) δ 11.5, CH_3; 135.0, C5; 137.3, C2, 139.7, C6; 150.2, C3; 171.8, C4; 183.7, C1. λ_{max} ($CHCl_3$) 277 nm (ε 10,700).

2,4-Dimethyl-6-nitrophenol (28c)

Nitric acid (10.3 ml; d 1.42) in acetic acid (40 ml) added dropwise to a stirred solution of 2,4-dimethylphenol (20 g) dissolved in acetic acid (100 ml) and held at 0°. The solution was then stirred 30 min. at 0° and 15 min. at 20° before being added to excess water (700 ml) and extracted with ether. Repeated decantation with hot pet. ether removed much of the oily impurity from the extract. Final purification was obtained by silica gel column chromatography followed by recrystallisation from pet. ether to give yellow crystals of m.p. 71.5-73° (lit. 72°)[40]. ν_{max} (Nujol) 3220 (OH); 1626, 1599 (phenyl)); 1545 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 2.29, s, 2-CH_3, 4-CH_3; 7.20, m, J 3 Hz, H-C3; 7.64, m. J 3 Hz, H-C5; 10.73, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 15.6, 2-CH; 20.1, 4-CH_3; 122.5, C5; 129.8, C2; 130.1, C4; 140.1, C3; 152.2, C1; signal for C-NO_2 not observed.

Nitration of 2,4-Dimethyl-6-nitrophenol (28c)

The phenol (28c) (1 g) was added over 15 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50°, and the resulting solution stirred at 50° for a further 5 min. The solution was cooled and a few drops of water added to give a precipitate of 2,5-dimethyl-3,6-dinitro-1,4-benzoquinone (44) (40 mg; 3%) which on isolation by filtration and recrystallisation from dichloromethane-pet. ether had m.p. 175° (dec.). (Found C, 42.9; H, 2.9; N, 12.2% $C_8H_6N_2O_6$ requires C, 42.5; H, 2.7; N, 12.4%). ν_{max} (Nujol) 1678, 1674 (C=O); 1640 (C=C); 1552 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.20, s, 2-CH_3/5-CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 11.4, 2-CH_3/5-CH_3; 135.9, C2/C5; signals for C1, C3, C4, C6 not observed. λ_{max} ($CHCl_3$) 270 nm (ε 13100). Further addition of water to the aqueous filtrate gave a precipitate of 2,5-dimethyl-3-nitro-1,4-benzoquinone (29c) (0.180 g; 17%) which on isolation by filtration and recrystallisation from ether-pet. ether had m.p. 51-52°. (Found C, 52.6; H, 4.0; N, 7.8%. $C_8H_4NO_4$ requires C, 53.0; H, 3.9; N, 7.7%). ν_{max} (Nujol) 1673 (C=O); 1627 (C=C); 1538 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.08, s, 2-CH_3; 2.14, d, J 1.5 Hz, 5-CH_3; 6.75, q, J 1.5 Hz, H6. ^{13}C n.m.r. (CD_3COCD_3) δ 11.0, 2-CH_3; 15.2, 5-CH_3; 134.8, C6; 136.0, C2; 145.5, C5; 162.3, C3; 178.9, C4; 186.0, C1. λ_{max} ($CHCl_3$) 260 nm (ε 14600). Finally, addition of excess water to the filtrate and extraction with chloroform gave an oily residue (0.179 g), shown (infrared, ^1H n.m.r. spectra) to contain c. 10% of the nitroquinone (29c), the remainder being polar unidentified material.

Attempted Reaction of 2,5-Dimethyl-3-nitro-1,4-benzoquinone (29c) with Fuming Nitric Acid

Treatment of the nitroquinone (29c) (222 mg), as for the 2,4-dimethyl-6-nitrophenol (28c) above, resulted in the recovery of unreacted nitroquinone (29c) (174 mg). No trace of the dinitroquinone (44) was detected.

2,3,6-Tribromo-4-methylphenol (31)

To 4-methylphenol (20 g), iron dust (4 g) and chloroform (160 ml) in a darkened flask was added bromine (31.5 ml) in chloroform (40 ml) dropwise with stirring and some heating. The mixture was refluxed 45 min. before hot filtering and extracting with 3N sodium hydroxide. Acidification gave a precipitate of the 2,3,6-tribromo-4-methylphenol (31) which was isolated by filtration. The crude material was purified by silica gel column chromotography and recrystallised from chloroform-carbontetrachloride as white crystals of m.p. 97-8° (lit. 102°)[41]. ν_{mas} (Nujol) 3470 (OH); 1578, 1553 cm^{-1} (phenyl). ^{1}H n.m.r ($CDCl_3$) δ 2.38, s, CH_3, 7.33, s, H-C5; 5.83, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 23.9, CH_3; 109.0, C6; 115.3, C2; 127.0, C3; 133.1, C5; 133.5, C4; 150.8, C1.

2,3-Dibromo-4-methyl-6-nitrophenol (32)

Powdered sodium nitrite (2 g) was added over 15 min. to a stirred suspension of 2,3,6-tribromo-4-methylphenol (31) (5 g) in acetic acid (50 ml) at 20°. The resulting mixture was stirred at 20° for 45 min.,

during which time the suspended solid dissolved and a new precipitate formed. This precipitated material (3.13 g) was isolated by filtration, and further material (1.14 g) isolated after the addition of water to the filtrate. Recrystallisation of the crude product from chloroform-carbon tetrachloride gave 2,3-dibromo-4-methyl-6-nitrophenol (32), m.p. 120-122° (lit. 124°)[26]. ν_{max} (Nujol) 3200, br. (OH); 1610 (phenyl); 1531 cm-1 (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.51, s, CH_3; 8.00, s, H5; 11.2, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 22.1, CH_3; 115.6, C2; 123.0, C5; 130.3, C4; 135.9, C4; 149.3, C1; signal for C-NO_2 not detected.

Nitration of 2,3-Dibromo-4-methyl-6-nitrophenol (32)

2,3-Dibromo-4-methyl-6-nitrophenol (32) (1g) was added over 15 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50°. The resulting solution was stirred at 50° for a further 5 min., the solution cooled and water added dropwise. 2,3-Dibromo-5-methyl-6-nitro-1,4-benzoquinone (34) (265 mg) was isolated by filtration and recrystallised from carbon tetrachloride - chloroform to give pure material, m.p. 194-195° (dec.) (lit. softens 165°, m.p. 175-180° (dec.))[26]. (Found: C, 25.9; H, 0.8; Br, 48.9; N, 4.3%. $C_7H_3Br_2NO_4$ requires C, 25.9; H, 0.9; Br. 49.2; N, 4.3%) ν_{max} (Nujol) 1676 (C=O); 1550 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.21, s, CH_3. ^{13}C n.m.r. Satisfactory spectra could not be obtained. λ_{max} ($CHCl_3$) 284, 368 nm (ε 13,200, 1,400).

Additions of water to the above filtrate gave a mixture (137 mg; 7:3) of the above quinone (34) and

2,3-dibromo-4-methyl-4-nitrato-6-nitrocyclohexa-2,5-dienone (33). Further addition of water gave the pure nitrato dienone (33) (68 mg), recrystallised from dichloromethane - petroleum ether, m.p. 101-103°. (Found: C, 22.9; H, 1.1; Br, 42.7; N, 7.4%. $C_7H_4Br_2N_2O_6$ requires C, 22.6; H, 1.1; Br, 43.0; N, 7.5%) ν_{max} (Nujol) 1701 (C=O); 1661, 1279, 831 ($-ONO_2$); 1546 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.85, s, CH_3; 7.73, s, H5. ^{13}C n.m.r. (CD_3COCD_3) δ 25.2, CH_3; 82.0, C4; 129.7, C2; 142.6, C5; 147.6, C3; no signals were detected for C1 and C6. λ_{max} ($CHCl_3$) 299 nm (ε 5,500).

Finally, the aqueous filtrate was extracted with chloroform to give an oil (124 mg) shown (t.l.c., infrared, ^1H n.m.r. spectra) to contain traces of the quinone (34) and the nitrato dienone (33).

The overall yields were: quinone (34) (392 mg; 38%), nitrato dienone (33) (134 mg; 11%), and unidentified material (87 mg).

2,3,6-Tribromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (49)

Fuming nitric acid (2 ml; d 1.5) was rapidly added to a stirred suspension of 2,3,6-tribromo-4-methylphenol (31) (2 g) in acetic acid (10 ml) at 20°. The red solution, so produced, was stored at 20° for 6 hours, by which time the solution was yellow in colour. Addition of water to the solution gave an oil which was collected; the decanted supernatant aqueous phase was extracted with chloroform and the extract combined with the oil, above. The components of the mixture were separated on a silica gel Chromatotron

plate to yield 2,3-dibromo-4-methyl-6-nitrophenol (32) (0.005 g); unidentified material (0.104 g) and 2,3,6-tribromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (49) (1.69 g) which recrystallised from dichloromethane - pet. ether as clear crystals of m.p. 127-129° (lit. 128°)[33] ν_{max} (Nujol) 3470 (OH); 1663 (C=O); 1620 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 1.65, s, CH_3; 7.53, s, H5; c. 2.8, s, OH. ^{13}C n.m.r (CD_3COCD_3) δ 27.9, CH_3; 74.8, C4; 119.2, C6; 125.7, C2; 154.2, C5; 157.0, C3; 171.2, C1. λ_{max} ($CHCl_3$) 265, 300 nm (ε 10600, 2100).

Nitration of 2,3,6-Tribromo-4-methylphenol (31)

2,3,6-Tribromo-4-methylphenol (31) (1 g) was added over 15 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50°. The resulting solution was stirred at 50° for a further 5 min., the solution cooled and water added dropwise. 2,3,5-Tribromo-1,4-benzoquinone (48) (232 mg) was isolated by filtration, and a further sample (77 mg) was isolated by extraction of the filtrate with chloroform and purification on a silica Chromatotron plate; the remaining components of the extract were polar oils (255 mg), shown (infrared, ^{1}H n.m.r. spectra) to be complex mixtures. The tribromo quinone (48) (total yield 31%) after recrystallisation from ether-pet. ether had m.p. 149-150° (lit. 152-153°)[30]. ν_{max} (Nujol) 1688, 1666 (C=O); 1612 cm^{-1} (C=C), ^{1}H n.m.r. ($CDCl_3$) δ 7.50, H6; ^{13}C n.m.r. (CD_3COCD_3) δ 136.2, C6; 138.2, 138.4, C2, C3; 140.2, C5; 171.7, C1; 176.4, C4. λ_{max} ($CHCl_3$) 300 nm (ε 10,700).

Nitration of 2,3,6-Tribromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (49)

2,3,6-Tribromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (49) (1 g) was added over 10 min. to stirred fuming nitric acid (4.5 ml, d 1.5) at 50°. The resulting solution was stirred at 50° for a further 5 min., the solution cooled and water added dropwise to deposit 2,3,5-tribromo-1,4-benzoquinone (48) (0.208 g), isolated by filtration. A further crop of the above quinone (48) (0.103 g) was isolated in a similar manner before extracting the filtrate with chloroform. The extract (0.153 g) was separated by silica gel Chromatotron plate to give more quinone (48) (17 mg) and starting material (49) (20mg) with the remaining material consisting of a complex mixture of polar oils.

2,6-Dibromo-4-methylphenol (50)

Bromine (5.0 ml) in acetic acid (5 ml) was added dropwise to a stirred solution of 4-methylphenol (5.0 g) and acetic acid (40 ml) in the dark at 20°. After stirring 30 min. excess water (160 ml) was added to give a precipitate of 2,6-dibromo-4-methylphenol (50) which was isolated by filtration. Recrystallisation from pet. ether gave white crystals of m.p. 45.5-47.5° (lit. 54°)[41]. ν_{max} (Nujol) 3550 (OH); 1562 cm^{-1} (phenyl). ^{1}H n.m.r. ($CDCl_3$) δ 2.23, s, CH_3; 7.20, s, arom. protons; 5.67, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 19.8, CH_3; 111.2, C2/C6; 133.0, C3/C5; 133.4, C4; 149.2; C1.

2,6-Dibromo-4-methyl-4-nitrocyclohexa-2,5-dienone (53)

Fuming nitric acid (1 ml; d 1.5) was added over 30 s to a stirred solution of 2,6-dibromo-4-methylphenol (50) (1 g) in acetic acid (3 ml) at 0°, and the resulting mixture stirred at 0° for a further 5 min. before adding a little water and cooling to deposit the nitrodienone (53) (0.95 g) isolated by filtration. The 4-nitrodienone (53) had m.p. 67-68° (dec.) (lit. 62° (dec.))[33]. ν_{max} (Nujol) 1690 (C=0); 1601 (C=C); 1561 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.00, s, CH_3; 7.58, s, H3/H5.

2,6-Dibromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (54)

2,6-Dibromo-4-methyl-4-nitrocyclohexa-2,5-dienone (53) (0.941 g) was added to acetic acid (3 ml) and stirred at 20° for 12 hours. Excess water was added and the crude product (0.792 g) extracted with chloroform. Separation of the extract by silica gel Chromatotron plate gave 2-bromo-4-methyl-6-nitrophenol (28b) (0.125 g); and 2,6-dibromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (54), (0.399 g) which recrystallised from chloroform-carbon-tetrachloride with m.p. 133.5-135° (lit. 134-135°)[33]. ν_{max} (Nujol) 3470 (OH); 1676, 1669 (C=0); 1601, 1591 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 1.55, s, CH_3, 7.37, s, H3/H5; c. 3.3, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 26.4, CH_3; 72.0, C4; 120.2, C2/C6; 154.7, C3/C5; 172.4, C1. λ_{max} ($CHCl_3$) 258 nm (ε 9350).

Nitration of 2,6-Dibromo-4-methylphenol (50)

2,6-Dibromo-4-methylphenol (50) (1 g) was added over 15 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50°. The resulting solution was stirred at 50° for a further 5 min., the solution cooled at 20° and water added. Extraction of the aqueous mixture with chloroform gave a yellow oil (746 mg), the components of which were separated on a silica Chromatotron plate. The least polar product, 2,6-dibromo-1,4-benzoquinone (51) (162 mg; 16%) recrystallised from ether-pet. ether with m.p. 130-131° (lit. 131-132°)[31]. ν_{max} (Nujol) 1694, 1657 (C=O); 1617 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 7.34, H3, H5; ^{13}C n.m.r. (CD_3COCD_3) δ 135.9, C3/C5; 139.1, C2/C6; 173.4, C1; 183.5, C4. λ_{max} ($CHCl_3$) 293, 358 nm (ε 12,000, 850).

The second compound eluted was (Z)-3-bromo-5-(bromonitromethylene)-2(5H)-furanone (52) (140 mg; 12%), m.p. 121-122.5° (from ether-light petroleum). ν_{max} (Nujol) 1793 (C=O); 1604 (C=C); 1519 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 8.55, H4; ^{13}C n.m.r. (CD_3COCD_3) δ 117.25, $\underline{C}BrNO_2$; 122.8, C3; 140.4, C4; 156.5, C5; 162.6, C2. λ_{max} ($CHCl_3$) 253 nm, 344 nm (ε 4,600, 16,200).

The third compound eluted was 5-bromo-2-methyl-3-nitro-1,4-benzoquinone (29b) (61 mg; 6%).

Nitration of 2,6-Dibromo-4-methyl-4-nitrocyclohexa-2,5-dienone (53)

The nitrodienone (53) (195 mg) was added over 5 min. to stirred fuming nitric acid (0.6 ml; d 1.5) at 50-53°. The solution was stirred for a further 5 min. at 50-53°, cooled, water added and the crude product (55 mg)

extracted using chloroform. This crude product was shown (infrared, ^{1}H m.n.r. spectra, t.l.c.) to contain the lactone (52), 2,6-dibromo-1,4-benzoquinone (51), 5-bromo-2-methyl-3-nitro-1,4-benzoquinone (29b), and highly polar compounds.

2,4,6-Tribromophenol

Bromine (33 ml) was added dropwise to a stirred solution of phenol (20 g) and water (400 ml) in the dark at 5°. The suspension was stirred a further 90 min. before filtering to yield the crude 2,4,6-tribromophenol. Recrystallisation from pet. ether gave crystals of m.p. 88-90° (lit. 95°)[42]. ν_{max} (Nujol) 3400 (OH); 3080 (C-H); 1557 cm^{-1} (phenyl). ^{1}H n.m.r. ($CDCl_3$) δ 7.63, s, arom. protons; 5.83, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 112.3, 112.5, C4, C2/C6; 135.1, C3/C5; 151.4, C1.

Nitration of 2,6-Dibromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (54)

The 4-hydroxydienone (54) (244 mg) was added over 15 min. to stirred fuming nitric acid (0.75 ml; d 1.5) at 50-52°. The solution was stirred for a further 5 min. at 50-52°, cooled, water added and the crude product (175 mg) isolated by extraction with chloroform. Fractional crystallisation of the crude product from ether - light petroleum gave the lactone (52) (79 mg) and 2,6-dibromo-1,4- benzoquinone (51) (20 mg), identical with authentic samples.

2,6-Dibromo-1,4-benzoquinone (51)

2,4,6-Tribromophenol (2 g) was added over 3 min. to stirred fuming nitric acid (20 ml; d 1.5) at 0°. The resulting solution was stirred 15 min. at 0° before being poured over ice (100 g). The precipitate of 2,6-dibromo-1,4-benzoquinone (51) (1 g) obtained was isolated by filtration and recrystallised from ether-petroleum ether.

Attempted Reaction of 2,6-Dibromo-1,4-benzoquinone (51) with Fuming Nitric Acid

The dibromo-1,4-benzoquinone (51) (489 mg) was added over 5 min. to stirred fuming nitric acid (2.2 ml, d 1.5) at 50-53°. The solution was stirred at 50-53° for a further 15 min., cooled to 20°, and water added. Two crops of crystalline 2,6-dibromo-1,4-benzoquinone (51) (total 387 mg) were isolated by filtration and a further sample (44 mg) was obtained by chloroform extraction of the filtrate. No evidence was found of the presence in the crude chloroform extract of lactone (52). The total recovery of 2,6-dibromo-1,4-benzoquinone (51) was c. 88%.

2,3,5,6-Tetrabromo-4-methylphenol (55)

To 4-methylphenol (30g), iron dust (10 g) and chloroform (250 ml) in a darkened flask was added bromine (61 ml) in chloroform (50 ml) dropwise with stirring and some heating. The mixture was refluxed 1½ hours before hot filtering and extracting with 2M sodium hydroxide. Acidification gave a precipitate of 2,3,5,6-tetrabromo-4-methylphenol (55) which was isolated by filtration and recrystallised from chloroform as white crystals of m.p. 198-199° (lit. 196°)[43]. ν_{max} (Nujol) 3430 (OH); 1555, 1530 cm^{-1} (phenyl). ^1H n.m.r. ($CDCl_3$) δ 2.73, s, CH_3; 6.08, s, OH. ^{13}C n.m.r. (CD_3COCD_3; $Cr(acac)_3$) δ (CH_3 and solvent signals coincide); 114.9, C2/C6; 127.3, C3/C5; 132.8, C4; 151.8, C1

2,3,5,6-Tetrabromo-4-methyl-4-nitrocyclohexa-2,5-dienone (112)

Fuming nitric acid (5 ml; d 1.5) was added over 30 s to a stirred suspension of 2,3,5,6-tetrabromo-4-methylphenol (55) (5 g) in acetic acid (45 ml) at c. 5°, and the mixture was stirred at 20° for 15 min. before being left to stand for 30 min. The mixture was cooled and the deposited nitrodienone (112) (4.49 g) isolated by filtration. Further crops of nitrodienone (112) were obtained by addition of water to the filtrate. The 4-nitrodienone (112) (total 4.8 g) had m.p. 198-200° although it rearranged at c. 100° (lit. red at 90°, NO_2 loss at 100°)[33]. ν_{max} (Nujol) 1682 (C=O); 1607 (C=C); 1579, 1563 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.25, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3; -25°) δ not observed due to low solubility. λ_{max} ($CHCl_3$) 275, 307 nm (ε 10300, 1980).

2,3,5,6-Tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57)

2,3,5,6-Tetrabromo-4-methyl-4-nitrocyclohexa-2,5-dienone (112) (4.5 g) was suspended in acetic acid (26 ml) and heated at 50-60° for 1 hour. The red solution was then cooled to deposit the hydroxydienone (57) (2.33 g) isolated by filtration. A further crop of hydroxydienone (57) was obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (57) (total 2.84 g) from chloroform gave clear crystals of m.p. 209-212° (lit. 205°)[33]. ν_{max} (Nujol) 3400, 3260 (OH); 1675, 1668 (C=O); 1599, 1572 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 1.83, s, CH_3; 2.70, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 27.7, CH_3; 75.8, C4; 123.5, C2/C6; 152.7, C3/C5; 167.3, C1. λ_{max} ($CHCl_3$) 272, 309 nm (ε 11600, 3200).

Nitration of 2,3,5,6-Tetrabromo-4-methylphenol (55)

2,3,5,6-Tetrabromo-4-methylphenol (55) (1.01 g) was added over 10 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 53°. The resulting solution was stirred at 54° for a further 20 min., cooled, water added and the crude product (0.815 g) isolated by filtration. Separation by silica gel Chromatotron plate gave 2,3,5,6-tetrabromo-4-methyl-4-nitratocyclohexa-2,5-dienone (56) (0.38 g) which recrystallised from ether-pet. ether as pale yellow crystals of m.p. 153-153.5° (dec.). (Found C, 17.6; H, 0.8; Br, 66.1; N, 2.8. $C_7H_3Br_4N_1O_4$ requires C, 17.4; H, 0.6; Br, 65.9; N, 2.9%). ν_{max} (Nujol) 1675

(C=O); 1657 (ONO_2); 1599, 1572 (C=C); 1276, 824 cm^{-1} (ONO_2). ^1H n.m.r. ($CDCl_3$) δ 1.85, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 26.6, CH_3; 87.5, C4; 129.0, C2/C6; 146.4, C3/C5; signal for C1 not observed. λ_{max} ($CHCl_3$) 276, 308 nm (ε 12900, 2900); and 2,3,5,6-tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57) (0.43 g).

Nitration of 2,3,5,6-Tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57)

2,3,5,6-Tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57) (0.2 g) was added over 4 min. to stirred fuming nitric acid (1 ml; d 1.5) at 50°. The resulting solution was stirred at 50° for a further 7 min., cooled, water added and the crude product (0.173 g) isolated by filtration. Separation by silica gel Chromatotron plate gave 2,3,5,6-tetrabromo-4-methyl-4-nitratocyclohexa-2,5-dienone (56) (65 mg) and 2,3,5,6-tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57) (100 mg).

2,3,5-Tribromo-6-nitro-4-methylphenol (58)

Powdered sodium nitrite (4.88 g) was added over ½ hour to a stirred suspension of 2,3,5,6-tetrabromo-4-methylphenol (55) (10 g) in acetic acid (100 ml) at 20°. The mixture was stirred at 40-50° for 3 hours before adding excess water (300 ml) and isolating the resulting yellow precipitate (8.1 g) by filtration. Separation by silica gel column chromatography gave 2,3,5,6-tetrabromo-4-methylphenol (55) (2.85 g); 2,3,5-tribromo-6-nitro-4-methylphenol (58) (2.73 g) which recrystallised from

chloroform as pale yellow needle crystals of m.p. 159-161° (lit. 160°)[43]. ν_{max} (Nujol) 3440 (OH); 1580 (Phenyl); 1540 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.68, s, CH_3; 6.67, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 25.7, 4-CH_3; 114.3, C2; 116.9, C5; 129.9, C3; 132.8, C4; 146.0, C1; signal for C-NO_2 not detected; and a trace of 2,3,5,6-tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone (57) among the remaining polar red oils.

2,3,5-Tribromo-4-methyl-4,6-dinitrocyclohexa-2,5-dienone

Fuming nitric acid (1.2 ml; d 1.5) was added over 5 s to a stirred suspension of 2,3,5-tribromo-4-methyl-6-nitrophenol (58) (1.2 g) in acetic acid (6 ml) at 20°, and the mixture was stirred 10 min. before being left to stand 20 min. The mixture was cooled and the deposited nitrodienone (0.94 g) isolated by filtration. A further crop of nitrodienone was obtained by addition of water to the filtrate. The 4-nitrodienone (total 1.05 g) went red at c. 70° and melted at 115-117° (dec.). ν_{max} (Nujol) 1679 (C=O); 1574, 1574 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.33, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3; -25°) δ 25.6, CH_3; 96.3, C4; 131.6, C5; 132.4, C2; 141.5, C3; 166.5, C1; signal for C=C-NO_2 was not observed. λ_{max} ($CHCl_3$) 262, 306 nm (ε 10300, 3380).

2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60)

2,3,5-Tribromo-4-methyl-4,6-dinitrocyclohexa-2,5-dienone (1.11 g) was suspended in acetic acid (5 ml) and heated at 45-55° for 30 min. A little water was added to the solution which was then cooled to deposit the hydroxydienone (60) (0.56 g) isolated by filtration. A further crop of hydroxydienone (60) was obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (60) (total 0.70 g) from chloroform gave clear crystals of m.p. 157-159° (dec.). (Found C, 20.6; H, 1.0; Br, 58.9; N, 3.4. $C_7H_4Br_3N_1O_4$ requires C, 20.7; H, 1.0; Br, 59.1; N, 3.5%). ν_{max} (Nujol) 3470 (OH); 1669 (C=O); 1570 (C=C); 1540 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.87, s, CH_3; 3.08, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 29.3, CH_3; 76.6, C4; 126.0, C2; 144.9, C5; 156.5, C3; 167.2, C1; signal for C-NO_2 not observed. λ_{max} ($CHCl_3$) 261, 306 nm (ε 13800, 3990).

Nitration of 2,3,5-Tribromo-4-methyl-6-nitrophenol (58)

2,3,5-Tribromo-4-methyl-6-nitrophenol (58) (0.9 g) was added over 12 min. to stirred fuming nitric acid (4.1 ml; d 1.5) at 50-53°. The resulting solution was stirred at 50-53° for a further 5 min., cooled, water added and the precipitate of 2,3,5-tribromo-4-methyl-4-nitrato-6-nitrocyclohexa-2,5-dienone (59) (0.286 g), so obtained, isolated by filtration and recrystallised from chloroform-carbontetrachloride as crystals of m.p. 174-175° (dec.). (Found C, 18.6; H, 1.2; Br, 53.4; N, 6.0%. $C_7H_3Br_3N_2O_6$ requires C, 18.7; H, 0.7; Br, 53.2; N,

6.2%). ν_{max} (Nujol) 1688 (C=O); 1661 (ONO_2); 1572 (C=C); 1549 (NO_2); 1278, 825 cm^{-1} (ONO_2). ^1H n.m.r. ($CDCl_3$) δ 1.92, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 26.0, CH_3; 85.8, C4; 129.4, C2; 138.2, C5; 147.6, C3; 166.6, C1; signal for C-NO_2 not observed. λ_{max} ($CHCl_3$) 263, 305 nm (ε 14300, 4550). On addition of more water to the aqueous filtrate further material (0.498 g) was deposited, which on isolation by filtration proved to be 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60). Further 4-hydroxydienone (60) (0.129 g) was isolated by extraction of the filtrate with chloroform.

Nitration of 2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60)

2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60) (0.473 g) was added over 15 min. to stirred fuming nitric acid (2.2 ml; d 1.5) at 50-53°. The resulting solution was stirred at 50-53° for a further 5 min., cooled, a little water added and the precipitate of 2,3,5-tribromo-4-methyl-4-nitrato-6-nitrocyclohexa-2,5-dienone (59) (0.175 g) so obtained, isolated by filtration. On addition of more water to the aqueous filtrate further material (0.225 g) was deposited and on isolation by filtration was found to be 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60). The filtrate was extracted with chloroform to give material (0.071 g) identified by ^1H n.m.r. and infrared spectra as the 4-nitratodienone (59) (3:1) and the 4-hydroxydienone (60).

2,3,5,6-Tetrabromo-4-ethylphenol (61)

To 4-ethylphenol (50 g), iron dust (17 g) and chloroform (500 ml) in a darkened flask was added bromine (275 g) dropwise with stirring and some heating. The mixture was refluxed 1 hour before hot filtering and extracting with 2M sodium hydroxide. Acidification gave a precipitate of 2,3,5,6-tetrabromo-4-ethylphenol (61) which was isolated by filtration and recrystallised from chloroform as white needle crystals of m.p. 107-108° (lit. 110°)[34]. ν_{max} (Nujol) 3420 (OH); 1551, 1523 cm^{-1} (Phenyl). ^{1}H n.m.r. ($CDCl_3$) δ 1.14, t, J 7 Hz, CH_3; 3.16, q, J 7 Hz, CH_2; 6.03, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 12.7, CH_3; 34.6, CH_2; 115.1, C2/C6; 126.8, C3/C5; 137.9, C4; 151.8, C1.

2,3,5,6-Tetrabromo-4-ethyl-4-nitrocyclohexa-2,5-dienone

Fuming nitric acid (5 ml; d 1.5) was added over 1 min. to a stirred suspension of 2,3,5,6-tetrabromo-4-ethylphenol (61) (5 g) in acetic acid (40 ml) at 20°, and the mixture was stirred 15 min. before being left to stand for 30 min. The mixture was cooled and the deposited nitrodienone (2.78 g) isolated by filtration. Further crops of nitrodienone were obtained by addition of water to the filtrate. The 4-nitrodienone (total 4.9 g) had m.p. 91-92° (dec.). (Found C, 20.0; H, 0.8; Br, 66.0; N, 2.7. $C_8H_5Br_4N_1O_3$ requires C, 19.9; H, 1.0; Br, 66.2; N, 2.9%). ν_{max} (Nujol) 1690 (C=O); 1602 (C=C); 1573, 1561 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 0.75, t, J 7.5 Hz, CH_3; 2.79, q, J 7.5 Hz, CH_2. ^{13}C n.m.r.

(CD_3COCD_3; -25°) δ 7.3, CH_3; 32.6, CH_2; 101.4, C4; 132.6, C2/C6; 140.0, C3/C5; signal for C=O not observed. λ_{max} ($CHCl_3$) 274, c.310 nm (ε c.15000, c.2800).

2,3,5,6-Tetrabromo-4-ethyl-4-hydroxycyclohexa-2,5-dienone (63)

2,3,5,6-Tetrabromo-4-ethyl-4-nitrocyclohexa-2,5-dienone (4.4 g) was suspended in acetic acid (20 ml) and heated at 50-60° for 1 hour. A little water was added to the red solution which was then cooled to deposit the hydroxydienone (63) (3.13 g) isolated by filtration. A further crop of hydroxydienone (63) was obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (63) (total 3.45 g) from chloroform-carbontetrachloride gave white needle crystals of m.p. 139-141° (lit. 139-140°)[34]. ν_{max} (Nujol) 3460 (OH); 1666 (C=O); 1601, 1595, 1575, 1563 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 0.61, t, J 7 Hz, CH_3; 2.21, q, J 7 Hz, CH_2; 3.10, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 7.6, CH_3; 35.6, CH_3; 82.3, C4; 126.9, C2/C6; 153.8, C3/C5; 170.0, C1. λ_{max} ($CHCl_3$) 272, 309 nm (ε 12440, 2410).

Nitration of 2,3,5,6-Tetrabromo-4-ethylphenol (61)

2,3,5,6-Tetrabromo-4-ethylphenol (61) (1 g) was added over 20 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50-55°. The resulting solution was stirred at 50-55° for a further 5 min., excess water added and the crude product (1.07 g) extracted with chloroform.

Separation by silica gel Chromatotron plate gave 2,3,5,6-tetrabromo-4-ethyl-4-nitratocyclohexa-2,5-dienone (62) (0.195 g) which recrystallised from ether-petroleum ether with m.p. 118-119°. (Found C, 19.3; H, 1.1; Br, 64.2; N, 2.7. $C_8H_5Br_4NO_4$ requires C, 19.3; H, 1.0; Br, 64.1; N, 2.8%). ν_{max} (Nujol) 1683 (C=O); 1652 (ONO_2); 1598, 1571 (C=C); 1273, 831 cm^{-1} (ONO_2). ^1H n.m.r. ($CDCl_3$) δ 0.70, t, J 7 Hz, CH_3; 2.16, q, J 7 Hz, CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 6.5, CH_3; 31.9, CH_2; 91.3, C4; 129.8, C2/C6; 145.3, C3/C5; 169.6, C1. λ_{max} ($CHCl_3$) 276, 305 nm (ε 16300, 3230); 2,3,5-tribromo-4-ethyl-6-nitrophenol (64) (0.048 g) and 2,3,5,6-tetrabromo-4-ethyl-4-hydroxycyclohexa-2,5-dienone (63) (0.651 g).

Nitration of 2,3,5,6-Tetrabromo-4-ethyl-4-hydroxycyclohexa-2,5-dienone (63)

2,3,5,6-Tetrabromo-4-ethyl-4-hydroxydienone (63) (0.3 g) was added over 10 min. to stirred fuming nitric acid (1.4 ml; d 1.5) at 50-53°. The resulting solution was stirred at 50-53° for a further 10 min., cooled, water added and the crude product (0.27 g) isolated by filtration. Separation by silica gel Chromatotron plate gave 2,3,5,6-tetrabromo-4-ethyl-4-nitratocyclohexa-2,5-dienone (62) (0.173 g) and 2,3,5,6-tetrabromo-4-ethyl-4-hydroxycyclohexa-2,5-dienone (63) (0.096 g).

2,3,5-Tribromo-4-ethyl-6-nitrophenol (64)

Powdered sodium nitrite (2.36 g) was added over ½ hour to a stirred suspension of 2,3,5,6-tetrabromo-4-ethylphenol (61) (10 g) in acetic acid (100 ml) at 20°. The orange solution was stirred a further 2 hours before adding excess water and extracting with dichloromethane. After redissolving the extract in ether-benzene the residues of acetic acid were removed by washing with water. Separation by silica gel column chromatography gave 2,3,5,6-tetrabromo-4-ethylphenol (61) (3.5 g); 2,3,5-tribromo-4-ethyl-6-nitrophenol (64) (3.5 g) which recrystallised from ether-petroleum ether as orange crystals of m.p. 127-128° (dec.) (lit. 122-3°)[34]. ν_{max} (Nujol) 3410 (OH); 1584 (phenyl); 1535 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.17, t, J 7.5 Hz, CH_3; 3.15, q, J 7.5 Hz, CH_2; 6.65, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 12.6, CH_3; 32.9, CH_2; 113.9, C2; 117.4, C5; 129.4, C3; 137.8, C4; 146.2, C1; signal for $\underline{C}$-NO_2 not observed; and 2,3,5,6-tetrabromo-4-ethyl-4-hydroxycyclohexa-2,5-dienone (63) (0.5 g).

2,3,5-Tribromo-4-ethyl-4,6-dinitrocyclohexa-2,5-dienone

Fuming nitric acid (5 ml; d 1.5) was added over 2 min. to a stirred suspension of 2,3,5-tribromo-4-ethyl-6-nitrophenol (64) (5 g) in acetic acid (15 ml) at 20°, and the mixture was stirred 15 min. before being left to stand 30 min. The mixture was cooled and the deposited nitrodienone (4.66 g) isolated by filtration. A further crop of nitrodienone was obtained by addition of water to

the filtrate. The 4-nitrodienone (total 4.83 g) had m.p. 92-93° (dec.). (Found C, 21.4; H, 0.9; Br, 53.0; N, 5.5. $C_8H_5Br_3N_2O_5$ requires C, 21.4; H, 1.1, Br, 53.4; N, 6.2%). ν_{max} (Nujol) 1692 (C=O); 1642 (C=C); 1575, 1550 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 0.83, t, J 7 Hz, CH_3; 2.82, q, CH_2. ^{13}C n.m.r. (CD_3COCD_3; -25°) δ 7.2, CH_3; 32.7, CH_2; 99.7, C4; 132.0, C2; 132.9, C5; 140.9, C3; 151.7, C6; 166.4, C1. λ_{max} ($CHCl_3$) 263, 309 nm (ε 9050, 3000).

2,3,5-Tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66)

2,3,5-Tribromo-4-ethyl-4,6-dinitrocyclohexa-2,5-dienone (4.56 g) was suspended in acetic acid (20 ml) and heated at 50-60° for 1 hour. A little water was added to the solution which was then cooled to deposit the hydroxydienone (66) isolated by filtration. Recrystallisation from chloroform gave the 4-hydroxydienone (66) (2.43 g) as clear crystals of m.p. 140-142°. (Found C, 22.9; H, 1.4; Br, 56.9; N, 3.3. $C_8H_6Br_3N_1O_4$ requires C, 22.9; H, 1.4; Br, 57.1; N, 3.3%). λ_{max} (Nujol) 3540 (OH); 1677 (C=O); 1645, 1570 (C=C); 1543 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 0.71, t, J 8 Hz, CH_3; 2.27, q, J 8 Hz, CH_2; 3.13, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 7.4, CH_3; 35.4, CH_2; 80.5, C4; 126.9, C2; 143.8, C5; 155.5, C3; 167.4, C1; signal for $\underline{C}$-NO_2 not observed. λ_{max} ($CHCl_3$) 262, 307 nm (ε 14800, 4070).

Nitration of 2,3,5-Tribromo-4-ethyl-6-nitrophenol (64)

2,3,5-Tribromo-4-ethyl-6-nitrophenol (64) (1 g) was added over 15 min. to stirred fuming nitric acid (4.5 ml; d 1.5) at 50-53°. The resulting solution was stirred at 50-53° for a further 5 min., cooled and water added to deposit a precipitate (0.294 g) isolated by filtration. The filtrate was extracted with chloroform. Separation of the combined reaction product (total 1.1 g) on a silica gel Chromatotron plate gave 2,3,5-tribromo-4-ethyl-4-nitrato-6-nitrocyclohexa-2,5-dienone (65) (0.219 g) which recrystallised from chloroform-carbontetrachloride with m.p. 140-141°. (Found C, 20.9; h, 1.1; Br, 51.7; N, 5.9. $C_8H_5Br_3N_2O_6$ requires C, 20.7; H, 1.1; Br, 51.6; N, 6.0%). ν_{max} (Nujol) 1687 (C=O), 1658 (ONO_2); 1570 (C=C); 1550 (NO_2); 1274, 830 cm^{-1} (ONO_2). ^1H n.m.r. ($CDCl_3$) δ 0.80, t, J 7 Hz, CH_3; 2.22, q, J 7 Hz; CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 6.5, CH_3; 32.2, CH_2; 89.3, C4; 130.1, C2; 137.5, C5; 146.9, C3; 166.7, C1; signal for $\underline{C}$-NO_2 not observed. λ_{max} ($CHCl_3$) 263.5, 308 nm (ε 16200, 4920); and 2,3,5-tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66) (0.617 g).

Nitration of 2,3,5-Tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66)

2,3,5-Tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66) (0.3 g) was added over 15 min. to stirred fuming nitric acid (1.4 ml; d 1.5) at 50-53°. The resulting solution was stirred at 50-53° for a further 5 min., cooled, a little water added, and the 2,3,5-tribromo-4-ethyl-4-nitrato-6-nitrocyclohexa-2,5-dienone (65)

(0.147 g) so obtained was isolated by filtration. The addition of more water to the filtrate deposited a precipitate of 2,3,5-tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66) (0.105 g) isolated by filtration. The filtrate was then extracted with chloroform, and this extract (0.053 g) separated by silica gel Chromatotron plate to give 2,3-dibromo-5-ethyl-6-nitro-1,4-benzoquinone (67) (5 mg) and the 4-hydroxydienone (66) (23 mg) with the remaining material consisting of a complex mixture of polar oils.

Acid Treatment of 2,3,5,6-Tetrabromo-4-ethyl-4-hydroxy-cyclohexa-2,5-dienone (63)

Powdered 2,3,5,6-tetrabromo-4-ethyl-4-hydroxy-cyclohexa-2,5-dienone (63) (0.5 g) was added to sulphuric acid (4 ml; d 1.84) and stirred 1 hour at 20° before being left to stand 17 hours. Water was added and the suspension cooled to precipitate the crude product (0.436 g) which was isolated by filtration. Separation of this on a silica gel Chromatotron plate gave 2,3,6-tribromo-5-ethyl-1,4-benzoquinone (71) (0.222 g) which recrystallised from ether-petroleum ether as yellow crystals of m.p. 117-118° (lit. 118-120°)[34]. ν_{max} (Nujol) 1678, 1664 (C=O); 1568 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 1.13, t, J 7 Hz, CH_3; 2.77, q, J 7 Hz, CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 11.9, CH_3; 26.1, CH_2; 134.3, C5; 138.1, 140.1, C2, C3; 151.0, C6; 171.8, C1; 175.6, C4. λ_{max} ($CHCl_3$) 304.5 nm (ε 23900); and 2,3,5,6-tetrabromo-4-ethylphenol (61) (0.129 g).

The reaction above was repeated with the sulphuric acid diluted by 10%. Separation gave the above benzoquinone (71) (0.250 g) and the above phenol (61) (0.136 g). With the sulphuric acid diluted by 20% the reaction gave the benzoquinone (71) (0.169 g), the phenol (61) (0.025 g) and the above 4-hydroxydienone (63) (0.217 g).

Acid Treatment of 2,3,5-Tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66)

Powdered 2,3,5-tribromo-4-ethyl-4-hydroxy-6-nitrocyclohexa-2,5-dienone (66) (0.5 g) was added to stirred sulphuric acid (4 ml; d 1.84) and stirred 1 hour at 20° before being left to stand 16 hours. Water was added and the suspension cooled to precipitate the crude product (0.35 g) which was isolated by filtration. Separation of this on a silica gel Chromatotron plate gave 2,3-dibromo-5-ethyl-6-nitro-1,4-benzoquinone (67) (0.208 g) which recrystallised from ether-petroleum ether as yellow crystals of m.p. 103-104°. (Found C, 28.5; H, 1.6; Br, 46.9; N, 4.1. $C_8H_5Br_2N_1O_4$ requires C, 28.4; H, 1.5; Br, 47.2; N, 4.1%). ν_{max} (Nujol) 1679 (C=O); 1552, 1534 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.19, t, J 8 Hz, CH_3; 2.55, q, J 8 Hz, CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 13.1, CH_3; 21.4, CH_2; 137.3, C5; 141.2, 141.2, C2, C3; 170.5, C4; 177.0, C1; signal for $\underline{C}$-NO_2 not observed. λ_{max} ($CHCl_3$) 287, 378 nm (ε 10,400, 1110); and 2,3-dibromo-5-ethyl-6-nitro-1,4-hydroquinone (72) (0.139 g) which recrystallised from ether-petroleum ether with m.p. 158-159°. (Found C, 28.4; H, 2.4; Br, 46.9; N, 4.0.

$C_8H_7Br_2N_1O_4$ requires C, 28.2; H, 2.1; Br, 46.9; N, 4.1%). ν_{max} (Nujol) 3520, 3400 (OH); 1599, 1570 (C=C); 1530 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.23, t, J 7 Hz, CH_3; 2.76, q, J 7 Hz, CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 13.9, CH_3; 21.2, CH_2; 113.8, C2; 125.0, C3; 140.6, C5; 142.7, C1; 147.3, C4; signal for C-NO_2 not observed.

Reduction of 2,3-Dibromo-5-ethyl-6-nitro-1,4-benzoquinone(67)

A suspension of stannous chloride (0.2 g) in water (5 ml) was added to 2,3-dibromo-5-ethyl-6-nitro-1,4-benzoquinone(67) (0.05 g) in acetic acid (1 ml) at 5° and slowly warmed to 20° over 1 hour. Water was added to the mixture and the precipitate of 2,3-dibromo-5-ethyl-6-nitro-1,4-hydroquinone(72) (0.049 g) isolated by filtration.

Acid Treatment of 2,3,5,6-Tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone(57)

Powdered 2,3,5,6-tetrabromo-4-hydroxy-4-methylcyclohexa-2,5-dienone(57) (1 g) was added to stirred sulphuric acid (8 ml; d 1.84) at 20°. The resulting mixture was stirred in the dark for 14 hours before being poured over ice-water. The resulting precipitate (0.942 g) was isolated by filtration and recrystallised from acetone. This material was identified as 2,3,5,6-tetrabromo-4-hydroxybenzenemethanol(70), m.p. 175-180° [the melt resolidified and subsequently had m.p. 270° (dec.)], ν_{max} (Nujol) 3500 (OH); 1542, 1512 cm^{-1} (phenyl). ^1H n.m.r. (CD_3COCD_3) δ 5.12, s, CH_2. ^{13}C n.m.r. (CD_3COCD_3; $Cr(acac)_3$) δ 68.7, CH_2; 115.3, C3′/C5′; 128.5, C2′/C6′; 134.3, C1′; 153.3, C4′. Analytical data in Table 5.

Acid Treatment of 2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone(60)

Powdered 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone(60) (0.26 g) was added to stirred sulphuric acid (2 ml; d 1.84) at 20°. The resulting mixture was stirred at 20° in the dark for 25 min., poured over ice-water and the resulting precipitate isolated by filtration. The filtrate was extracted with chloroform. Separation of the combined material on a silica gel Chromatotron plate gave:

(i) an unidentified compound (59 mg) which recrystallised from ether-petroleum ether as orange-red needles of m.p. 143-4°. (Found C.I. (ISOB) MH^+ 326; high resolution mass 324.856220, $C_7H_5NO_4Br_2^{79}$ requires 324.858630; Br_2 isotope pattern observed). ν_{max} (Nujol) 1598; 1564 cm^{-1}. ^1H n.m.r. ($CDCl_3$) δ 2.43 (3H); 10.97 (1H); 11.08 (1H).

(ii) 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone(60) (45 mg).

(iii) 2,3,6-tribromo-4-hydroxy-5-nitrobenzenemethanol(75) (46 mg) which recrystallised from ether-petroleum ether as a tan powder of m.p. 170-1° (dec.). Analytical data in Table 5. ν_{max} (Nujol) 3410 (OH); 1576 (phenyl); 1540 cm^{-1} (NO_2). ^1H n.m.r. (CD_3COCD_3) δ 5.08, s, CH_2.

Base Treatment of 2,3,5,6-Tetrabromo-4-hydroxy-4-methyl-cyclohexa-2,5-dienone (57)

Powdered 2,3,5,6-tetrabromo-4-hydroxy-4-methyl-cyclohexa-2,5-dienone (57) (1 g) was added to a 10% aqueous solution of sodium hydroxide (4 ml). Sufficient ethanol (1.3 ml) was added to dissolve the solid and the solution was stirred at 20° for 1 hr. Acidification produced a precipitate of 2,3,6-tribromo-4,5-dihydroxy-4-methyl-cyclohexa-2,5-dienone (80) (0.95 g) which on isolation by filtration and recrystallisation from chloroform gave clear crystals of m.p. 154-155° and sometimes 173-175° (lit. 131°, 152°)[33]. (Found C, 21.3; H, 1.9; Br, 60.1 for the m.p. 173-175° crystals. C, 21.5; H, 1.4; Br, 59.9 for the m.p. 154-155° crystals. $C_7H_5Br_3O_3.1\ H_2O$ requires C, 21.3; H, 1.8; Br, 60.7%). ν_{max} (Nujol) 3560, 3480, 3320 (OH); 1608, 1598 (C=O); 1562 cm^{-1} (C=C). ^1H n.m.r. (CD_3COCD_3) δ 1.75, s, CH_3; 4.90, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 24.6, CH_3; 71.8, C4; 93.0, C6; 122.6, C2; 146.2, C3; 168.2, C1; 169.3, C5. λ_{max}(Dioxan) 218, 259, 312 nm (ε 14000, 16100, 3630).

Base Treatment of 2,3,5,6-Tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77)

Powdered 2,3,5,6-tetrachloro-4-hydroxy-4-methyl-cyclohexa-2,5-dienone (77) (0.3 g) was dissolved in stirred 6% aqueous solution of sodium hydroxide (3.5 ml) at 38-44° for 30 min., then stirred at 20° a further 30 min. Acidification produced an oily precipitate (0.06 g) isolated by filtration. On cooling the filtrate for several hours

another precipitate formed. After isolation by filtration and recrystallisation from chloroform this proved to be 2,3,6-trichloro-4,5-dihydroxy-4-methylcyclohexa-2,5-dienone (78) (0.16 g) of m.p. 149-150° (lit. 110°, 125°)[25]. (Found C, 32.2; H, 2.9; Cl, 40.8. $C_7H_5Cl_3O_3.1\ H_2O$ requires C, 32.2; H, 2.7; Cl, 40.7%). ν_{max} (Nujol) 3530, 3470, 3310 (OH); 1616, 1602 (C=O); 1569 cm^{-1} (C=C). ^1H n.m.r. (CD_3COCD_3) δ 1.76, s, CH_3; 5.48, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 23.5, CH_3; 70.8, C4; 103.8, C6; 126.4, C2; 147.6, C3; 167.5, C1; 168.8, C5. λ_{max} (Dioxan) 220, 250, 308 nm (ε 7940, 11200, 2520).

Base Treatment of 3,5,6-Tribromo-4-hydroxy-2,4-dimethyl-cyclohexa-2,5-dienone (81)

Powdered 3,5,6-tribromo-4-hydroxy-2,4-dimethyl-cyclohexa-2,5-dienone (81) (0.3 g) was added to a 10% aqueous solution of sodium hydroxide (1 ml). Sufficient ethanol (0.8 ml) was added to dissolve the solid and the solution was stirred at 20° for 1 hour. Acidification produced a precipitate of 3,6-dibromo-4,5-dihydroxy-2,4-dimethylcyclohexa-2,5-dienone (82) (0.22 g) which on isolation by filtration and recrystallisation from chloroform gave crystals that darkened at 184° and melted 191-192° (dec.). (Found C, 30.9; H, 2.7; Br, 51.0. $C_8H_8Br_2O_3$ requires C, 30.8; H, 2.6; Br, 51.2%). ν_{max} (Nujol) 3250, 3160 (OH); 1652, 1624, 1608 cm^{-1}. ^1H n.m.r. (CD_3COCD_3) δ 1.68, s, 4-CH_3; 2.04, s, 2-CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 17.0, 2-CH_3; 28.3, 4-CH_3; 74.0, C4; 98.9, C6; 134.0, C2; 146.8, C3; 172.4, C1; 177.7, C5. λ_{max} (Dioxan) 217, 250, 303 nm (ε 6770, 14200, 3470).

Base Treatment of 3,5-Dibromo-4-hydroxy-2,4,6-trimethyl-cyclohexa-2,5-dienone (84)

Powdered 3,5-dibromo-4-hydroxy-2,4,6-trimethyl-cyclohexa-2,5-dienone (84) (0.6 g) was added to a 10% aqueous solution of sodium hydroxide (2 ml). Sufficient ethanol (1.5 ml) was added to dissolve the solid and the solution was stirred at 20° for 23 hrs. Acidification produced a white precipitate of 3-bromo-4,5-dihydroxy-2,4,6-trimethyl-cyclohexa-2,5-dienone (85) (0.434 g) which on isolation by filtration and recrystallisation from chloroform gave crystals of m.p. 222-223° (dec.). (Found C, 43.6; H, 4.6; Br, 32.6. $C_9H_{11}Br_1O_3$ requires C, 43.8; H, 4.5; Br, 32.3%). ν_{max} (Nujol) 3270 (OH); 1663, 1620, 1601, 1580 cm^{-1}. ^1H n.m.r. (CD_3COCD_3) δ 1.62, s, 2-CH_3; 1.76, s, 4-CH_3, 2.00, s, 6-CH_3; 3.73, s, OH; 5.10, s, OH. ^{13}C n.m.r. (CD_3COCD_3) satisfactory spectra could not be obtained. λ_{max} (Dioxan) 216, 247, 299 nm (ε 6180, 14800, 3690).

Base Treatment of 2,3,5-Tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60)

Powdered 2,3,5-tribromo-4-hydroxy-4-methyl-6-nitrocyclohexa-2,5-dienone (60) (0.3 g) was added to a 10% aqueous solution of sodium hydroxide (1 ml) at 0°. Sufficient ethanol (0.5 ml) was added to dissolve the solid and the solution was stirred at 5° for 1 hr. Acidification produced a light brown oily solid (0.032 g) which was collected; the decanted supernatant aqueous phase was extracted with dichloromethane to give a yellow solid (0.103 g) which when washed with ether left

3,4-dibromo-5-methyl-5-(2´-nitroethan-1´-one)-2(5H)-furanone (86) (66 mg) as a white solid that recrystallised from chloroform as clear crystals, m.p. 173-4° (dec.). (Found C, 24.5; H, 1.4; Br, 46.3; N, 4.0. $C_7H_5Br_2N_1O_5$ requires C, 24.5; H, 1.5; Br, 46.6; N, 4.1%). ν_{max} (Nujol) 1778, 1744 (C=O); 1600 (C=C); 1563 cm^{-1} (NO_2). ^1H n.m.r. (CD_3COCD_3) δ 1.90, s, CH_3; 6.03, s, CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 21.8, CH_3; 81.3, C5; 92.9, C7; 118.1, C3; 146.9, C4; 165.3, C2; 192.4, C6. λ_{max} (Dioxan) 223, 246, 340 nm (ε 12600, 15600, 1000).

2,3,5,6-Tetrachloro-4-methylphenol (90)

2,3,5,6-Tetrachloro-4-methylphenol (90) was prepared in three steps. To p-toluidine (50 g) in acetic acid (400 ml) was added hydrochloric acid (80 ml; d 1.2). Chlorine gas was then bubbled through the solution for 3 hours. During the first hour the solution was cooled as the reaction is exothermic. The solution was then left to stand overnight before resuming the gas supply for a further 2½ hours. Ammonium chloride produced was removed by filtration and the solvent removed under reduced pressure to leave a yellow/orange oil.

To this oil (minus 5 g) was added acetic acid (600 ml) and potassium acetate (134 g). After heating 1 ¾ hours at 90-115° the black solution was added to excess water (c. 2.2 ℓ) and filtered to give a black solid (tar). This crude material was dissolved in petroleum ether and decanted so as to leave behind some unwanted residues and then passed through a short silica

gel column eluted with petroleum ether only. The solvent was removed to give an orange oil suitable for reduction to the phenol (90).

To this oil was added hydrochloric acid (700 ml; 2.7 M) and stannous chloride (257 g; mol. ratio 2.5:1). The suspension was next heated for 3 hours at 120° before cooling and isolating the crude phenol by filtration. This material was eluted through a short silica gel column using a mixture of 40% ether in petroleum ether before recrystallising from chloroform to give white needle crystals of 2,3,5,6-tetrachloro-4-methylphenol (90), m.p. 191-193° (lit. 190°)[25]. ν_{max} (Nujol) 3420 (OH); 1572, 1556 cm^{-1} (phenyl). ^{1}H n.m.r. ($CDCl_3$) δ 2.48, s, CH_3; 5.95, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 19.1, 4-CH_3; 120.5, C2/C6; 128.2, C3/C5; 132.4, C4; 149.8, C1.

2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87)

Fuming nitric acid (5 ml; d 1.5) was added over 30 s to a stirred suspension of 2,3,5,6-tetrachloro-4-methylphenol (90) (5 g) in acetic acid (42 ml) at 20°, and the mixture was stirred at 20° for 15 min. before being left to stand for 30 min. The mixture was cooled and the deposited nitrodienone (87) (2.48 g) isolated by filtration. Further crops of nitrodienone (87) were obtained by addition of water to the filtrate. The 4-nitrodienone (87) (total 4.1 g) had m.p. 82-83° (dec.) (lit. dec. at c. 80°, m.p. c. 90°)[25]. ν_{max} (Nujol) 1680 (C=O); 1614 (C=C); 1576 cm^{-1} (NO_2). ^{1}H n.m.r. ($CDCl_3$) δ 2.25, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3; $Cr(acac)_3$; -27°) δ 23.6, CH_3; 95.1, C4;

134.9, C2/C6; 143.5, C3/C5; 169.4, C1. λ_{max} ($CHCl_3$) 256, 290 nm (ε 12600, 2300).

Rearrangement of 2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in (D)-Chloroform

(a) Without added hydroquinone - A solution of the 4-nitrodienone (87) (500 mg) in $CDCl_3$ (5 ml) was stored in a darkened flask at 30° for 4.5 days. The solvent was removed under reduced pressure to give a crude product (420 mg) which was shown (^1H n.m.r.) to be a mixture (c. 3:2) of two compounds. These components were separated on a silica gel Chromatotron plate and gave 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) (128 mg; 33%) and 2,3,5,6-tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77) (249 mg; 56%).

(b) With added hydroquinone - A solution of the 4-nitrodienone (87) (500 mg) and hydroquinone (190 mg) in $CDCl_3$ (5 ml) was stored in a darkened flask at 30° for 2 days. The crude product, isolated as above, was separated into its components by silica gel Chromatotron plate as 2,3,5,6-tetrachloro-4-methylphenol (90) (237 mg; 56%); 2,3,5,6-tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77) (77 mg; 17%) and what is believed to be 1,2-di(2',3',5',6'-tetrachloro-4-hydroxybenzyl)ethane (91) (10 mg; 2.4%) with m.p. 176-8° (dec.). ν_{max} (Nujol) 3520 (OH); 1562, 1544 cm^{-1} (C=C).

2,3,5,6-Tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77)

2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) (4.13 g) was suspended in acetic acid (10 ml) and heated at 50-60° for 1 hour. A little water was added to the red solution which was then cooled to deposit the hydroxydienone (77) (1.25 g) isolated by filtration. Further crops of hydroxydienone (77) were obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (77) (total 2.14 g) from chloroform gave clear crystals of m.p. 168-169.5° (lit. 166°)[25]. ν_{max} (Nujol) 3410, 3330, 3250 (OH); 1681 (C=O); 1613, 1589 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 1.83, s, CH_3; 3.12, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 24.7, CH_3; 73.0, C4; 127.2, C2/C6; 153.0, C3/C5; 167.6, C1. λ_{max} ($CHCl_3$) 256, 298 nm (ε 14100, 2400).

2,5,6-Trichloro-3,4-dihydroxytoluene

Sulphuryl chloride (11.3 ml) was added dropwise to a stirred solution of 3,4-dihydroxytoluene (5.0 g) in ether (40 ml) at 20°. After stirring overnight the solution was washed with a bicarbonate solution to remove sulphuryl chloride residues. The ether solution was then evaporated and the crude 2,5,6-trichloro-3,4-dihydroxytoluene recrystallised from chloroform to give white needle crystals of m.p. 180.5-181.5° (lit. 182.5°)[44]. ν_{max} (Nujol) 3500, 3430, 3190 cm^{-1} (OH). ^{1}H n.m.r. ($CDCl_3$) δ 2.43, s, CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 18.1, CH_3; 119.3, 121.0, 123.7, 126.6, C1, C2, C5, C6; 142.3, 142.4, C3, C4.

3,4,6-Trichloro-5-methyl-1,2-benzoquinone (89)

Fuming nitric acid (0.2 ml, d 1.5) in acetic acid (1.2 ml) was added over 5 min. to a stirred solution of 2,5,6-trichloro-3,4-dihydroxytoluene (1 g) in ethanol (2.5 ml) at 0° in the dark, and the mixture was stirred at 0° for 15 min. and then at 3° for 30 min. before isolating the resulting precipitate (0.47 g) by filtration. The filtrate was evaporated to dryness and then washed repeatedly with a mixture of ether-petroleum ether which dissolved the remaining byproduct leaving behind pure bright red crystals of 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) of m.p. 104-104.5° (lit. 103°)[45]. ν_{max} (Nujol) 1680 (C=O); 1584 cm^{-1} (C=C). ^{1}H n.m.r. ($CDCl_3$) δ 2.53, s, CH_3. λ_{max} ($CHCl_3$) 457 nm (ε 1600) (lit. 457 nm (ε 1710))[44].

3,5-Dibromo-2,4,6-trimethylphenol (103)

Bromine (16 ml) was slowly added to a stirred solution of mesitol (20 g) and iodine (5 g) in acetic acid (100 ml). After stirring in the dark overnight excess water containing sodium thiosulphate was added and the suspension was cooled. The crude product (103) was isolated by filtration and recrystallised from chloroform as white needles of m.p. 155-157° (lit. 158-159°)[46]. ν_{max} (Nujol) 3360 (OH); 1570 cm^{-1} (phenyl). ^{1}H n.m.r. ($CDCl_3$) δ 2.36, s, 2 & 6-CH_3; 2.60, s, 4-CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 17.8, 2-CH_3/6-CH_3; 25.2, 4-CH_3; 125.4, 125.6, C2, C3, C5, C6; 129.1, C4; 152.3, C1.

3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95)

Fuming nitric acid (3 ml; d 1.5) was added over 1½ min. to a stirred suspension of 3,5-dibromo-2,4,6-trimethylphenol (103) (3 g) in acetic acid (15 ml) at c. 5°, and the mixture was stirred at c. 5° for 15 min. before being left to stand at 20° for 30 min. A little water was added and the mixture cooled to precipitate nitrodienone (95) (2.94 g) isolated by filtration. The 4-nitrodienone (95) had m.p. 70.5-72° (dec.). (Found C, 32.0; H, 3.0; Br, 47.2; N, 4.2. $C_9H_9Br_2N_1O_3$ requires C, 31.9; H, 2.7; Br, 47.1; N, 4.1%). ν_{max} (Nujol) 1665 (C=O); 1624 (C=C), 1566 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.15, s, 2-CH_3/6-CH_3, 4-CH_3. ^{13}C n.m.r. (CD_3COCD_3, -25°) δ 16.8, 2-CH_3/6-CH_3; 26.2, 4-CH_3; 95.3, C4; 137.1, C2/C6; 139.6, C3/C5; 179.3, C1. λ_{max} ($CHCl_3$) 253, 289 nm (ε 17200, 3700).

Rearrangement of 3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) in (D)-Chloroform

A solution of the 4-nitrodienone (95) (500 mg) in $CDCl_3$ (5 ml) was stored in a darkened flask at 30° for 4 days. The solvent was removed under reduced pressure and the crude product separated by silica gel Chromatotron plate to give the 4-nitrodienone (95) (112 mg; 22%) and 3,5-dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (294 mg; 64%).

3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) and 3,5-Dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104)

3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) (4 g) was dissolved in acetic acid (13 ml) and heated at 50-60° for 2 hours. A little water was added to the yellow solution which was then cooled to deposit the 4-hydroxydienone (84) (2.68 g) isolated by filtration. The filtrate was extracted with dichloromethane, separation of which by silica gel Chromatotron plate gave more of the 4-hydroxydienone (84) (0.294 g) which recrystallised from carbontetrachloride as clear crystals of m.p. 130.5-131.5° (lit. 132°)[47]. (Found C, 34.8; H, 3.4%. $C_9H_{10}Br_2O_2$ requires C, 34.9; H, 3.3%). ν_{max} (Nujol) 3430, 3270 (OH); 1639 cm^{-1} (C=O). ^1H n.m.r. ($CDCl_3$) δ 1.72, s, 4-CH_3; 2.10, s, 2-CH_3/6-CH_3. ^{13}C n.m.r. (CD_3COCD_3) δ 16.6, 2-CH_3/6-CH_3; 30.0, 4-CH_3; 73.6, C4; 134.7, C2/C6; 151.4, C3/C5; 180.3, C1. λ_{max} ($CHCl_3$) 254, 291 nm (ε 18300, 4600); and 3,5-dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (0.714 g) which recrystallised from carbontetrachloride-pentane as pale yellow needle crystals of m.p. 86-87°. (Found C 34.8; H, 3.4; Br, 51.1. $C_9H_{10}Br_2O_2$ requires C, 34.9; H, 3.3; Br. 51.6%). ν_{max} (Nujol) 3520, 3450 (OH); 1673 (C=O); 1618, 1555 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 1.44, s, 6-CH_3; 2.08, s, 2-CH_3; 2.33, s, 4-CH_3; 3.27, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 16.8, 2-CH_3; 24.5, 4-CH_3; 28.8, 6-CH_3; 77.9, C6; 129.9, C5; 132.8, C2, 136.3, C4; 142.5, C3; 199.4, C1. λ_{max} ($CHCl_3$) 249, 333 nm (ε 4720, 4020).

Rearrangement of 2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in benzene

A solution of the 4-nitrodienone (87) (500 mg) in benzene (8 ml) was stored in a darkened flask at 30° for 14 days. The solvent was removed under reduced pressure and the crude product separated by silica gel Chromatotron plate giving 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) (220 mg; 57%) and 2,3,5,6-tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (77) (116 mg; 26%).

Rearrangement of 3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) in Benzene

A solution of the 4-nitrodienone (95) (500 mg) in benzene (8 ml) was stored in a darkened flask at 30° for 1½ days. The solvent was removed under reduced pressure and the crude product separated by silica gel Chromatotron plate to give 3,5-dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (304 mg; 67%); 1-acetyl-3,c-5-dibromo-2,4-dimethyl-c-2,5-dinitrocyclopent-3-en-r-ol (97) (65 mg; 11%) recrystallised from ether-petroleum ether to give crystals of m.p. 127-8% (dec.). (Found C, 26.7; H, 2.5; N, 6.6. $C_9H_{10}Br_2N_2O_6$ requires C, 26.9; H, 2.5; N, 7.0%). ν_{max} (Nujol) 3440 (OH); 1720 (C=O); 1639 (C=C); 1562 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.71, s, 2-CH_3; 2.40, s, 4-CH_3; 2.44, s, acetyl-CH_3; 4.38, s, OH; and 1-acetyl-3, c-5-dibromo-c-2,4-dimethyl-2,5-dinitrocyclopent-3-en-r-ol (98) (17 mg; 3%) which recrystallised from ether-pet. ether as needle crystals with m.p. 140-141° (dec.) (lit. 141.5-142°)[37]. ν_{max} (Nujol) 3470 (OH); 1712 (C=O); 1632 (C=C); 1568 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.93, s, 2-CH_3; 2.28, s, 4-CH_3; 2.36, s, acetyl-CH_3; 4.64, s, OH.

Rearrangement of 2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in the Presence of 2,3,5,6-Tetrachloro-4-methylphenol (90) in Benzene Solution

A solution of the 4-nitrodienone (87) (500 mg; 1.73 mmole) and the tetrachlorophenol (90) (422 mg; 1.73 mmole) in benzene (8 ml) was stored in a darkened flask at 30° for 58 hours. The solvent was removed under reduced pressure, and the components of the crude product were separated on a silica gel Chromatotron plate to give;

(i) Tetrachlorophenol (90) (264 mg; 31%).

(ii) 2,3,5,6-Tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (88) (116 mg; 13%).

(iii) 3,4,6-Trichloro-5-methyl-1,2-benzoquinone (89) (26 mg; 3%).

(iv) 2,3,5,6-Tetrachloro-4-(nitromethyl)phenol (102) (327 mg; 33%) which recrystallised from dichloromethane-petroleum ether with m.p. 135-136°. (Found C, 28.8; H, 0.8; Cl, 48.5; N, 4.4. $C_7H_3Cl_4N_1O_3$ requires C, 28.9; H, 1.0; Br, 48.8; N, 4.8%). ν_{max} (Nujol) 3430 (OH); 1569, 1557, 1546 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 5.85, s, CH_2; c.5.0, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 74.1, CH_2; 119.7, C2/C6; 133.4, C3/C5; 151.6, C4; 164.0, C1.

Rearrangement of 3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) in the Presence of 3,5-Dibromo-2,4,6-methylphenol (103) in Benzene Solution

A solution of the 4-nitrodienone (95) (500 mg; 1.47 mmole) and the dibromophenol (103) (434 ml; 1.47 mmole) in benzene (8 ml) was stored in a darkened flask at 30° for

50 hours. A precipitate of 1,2-di(2′,6′-dibromo-4′-hydroxy-3′,5′-dimethylbenzyl)ethane (106) (33 mg; 4%) was isolated from the resulting mixture by filtration. The solvent was removed from the filtrate under reduced pressure and the components of the remaining crude product were separated on a silica gel Chromatotron plate to give:

(i) Dibromophenol (103) (296 mg; 34%).

(ii) 3,5-Dibromo-6-hydroxy-2,4,6-trimethycyclohexa-2,4-dienone (104) (93 mg; 10%).

(iii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (49 mg; 4.4%).

(iv) 3,5-Dibromo-2,6-dimethyl-4-(nitromethyl)phenol (105) (327 mg; 33%).

Rearrangement of 3,5-Dibromo-2,4,6-trimethyl-4-nitro-cyclohexa-2,5-dienone (95) in the Presence of 3,5-Dibromo-2,4,6-trimethylphenol (103) in (D)Chloroform Solution

A solution of the 4-nitrodienone (95) (500 mg; 1.47 mmole) and the dibromophenol (103) (434 mg; 1.47 mmole) in $CDCl_3$ (5 ml) was stored in a darkened flask at 30° for 53 hours. A precipitate of 1,2-di(2′,6′-dibromo-4′-hydroxy-3′,5′-dimethylbenzyl)-ethane (106) (39 mg; 4.5%) was isolated from the resulting mixture by filtration and recrystallised from acetone-petroleum ether with m.p. 293-295° (dec.). (Found C, 37.2; H, 3.1; Br, 54.4. $C_{18}H_{18}Br_4O_2$ requires C, 36.9; H, 3.1; Br, 54.5%). ν_{max} (Nujol) 3450 (OH); 1561 cm^{-1} (Phenyl). ^1H n.m.r. (CD_3COCD_3) δ 2.36, s, 3′-CH_3/5′-CH_3; 3.40, s, -CH_2-CH_2-. The solvent was removed from the reaction filtrate under reduced pressure and the

the components of the remaining crude product were separated on a silica gel Chromatotron plate to give:

(i) Dibromophenol (103) (183 mg; 21%)

(ii) 3,5-Dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (141 mg; 16%).

(iii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (38 mg; 4%).

(iv) 3,5-Dibromo-2,6-dimethyl-4-(nitromethyl)phenol (105) (250 mg; 25%) which recrystallised from dichloromethane-petroleum ether as white crystals of m.p. 136-137° (dec.) (lit. 127-128°)[48]. (Found C, 32.2; H, 2.5; Br, 46.9; N, 3.8. $C_9H_9Br_2N_1O_3$ requires C, 31.9; H, 2.7; Br, 47.1; N, 4.1%). ν_{max} (Nujol) 3530 (OH); 1552 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.37, s, 2-CH_3/6-CH_3; 5.22, s, OH; 5.97, s, 4-CH_2. ^{13}C n.m.r. (CD_3COCD_3) δ 17.6, 2-CH_3/6-CH_3; 81.6, 4-CH_2; 122.4, 126.1, 128.2, C2, C3, C4, C5, C6; 155.9, C1.

Rearrangement of 2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in the Presence of 3,5-Dibromo-2,4,6-trimethylphenol (103) in Benzene Solution

A solution of the 4-nitrodienone (87) (500 mg; 1.73 mmole) and the dibromophenol (103) (509 mg; 1.73 mmole) in benzene (8 ml) was stored in a darkened flask at 30° for 50 hours. The solvent was removed under reduced pressure, and the components of the crude product were separated on a silica gel Chromatotron plate to give:

(i) 2,3,5,6-Tetrachloro-4-methylphenol (90) (346 mg; 41%)

(ii) 3,5-Dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (54 mg; 5%)

(iii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (56 mg; 5%)

(iv) 2,3,5,6-Tetrachloro-4-(nitromethyl)phenol (102) (14 mg; 1.4%)

(v) 3,5-Dibromo-2,6-dimethyl-4-(nitromethyl)phenol (105) (210 mg, 18%)

(vi) 3,5-Dibromo-6-hydroxy-2,6-dimentyl-4-(nitromethyl)cyclohexa-2,4-dienone (108) (112 mg; 9%)

Rearrangement of 3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) in the Presence of 2,3,5,6-Tetrachloro-4-methylphenol (90) in Benzene Solution

A solution of the 4-nitrodienone (95) (506 mg; 1.49 mmole) and the tetrachlorophenol (90) (364 mg; 1.49 mmole) in benzene (8 ml) was stored in a darkened flask at 30° for 52 hours. The solvent was removed under reduced pressure, and the components of the crude product were separated on a silica gel Chromatotron plate to give:

(i) Tetrachlorophenol (90) (311 mg; 43%)

(ii) 3,5-Dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (35 mg; 4%)

(iii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (73 mg; 8%).

(iv) 3,5-Dibromo-2,6-dimethyl-4-(nitromethyl)phenol (105) (223 mg; 22%)

(v) What is believed to be 3,5-bromo-6-hydroxy-2,6-dimethyl-4-(nitromethyl)cyclohexa-2,4-dienone (108) (43 mg; 4%). ν_{max} (Nujol) 3480 (OH); 1679 (C=O); 1611 (C=C); 1562 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 1.56, s, 6-CH_3; 2.13, s, 2-CH_3; 5.69, s, 4-CH_2.

2,3,5-Tribromo-4,6-dimethylphenol

To 2,4-dimethylphenol (20 g), iron dust (7 g) and chloroform (170 ml) in a darkened flask was added bromine (30.5 ml) in chloroform (40 ml) dropwise with stirring and some heating. The mixture was refluxed 1½ hours before hot filtering and extracting with 2M sodium hydroxide. Acidification gave a precipitate of 2,3,5-tribromo-4,6-dimethylphenol which was isolated by filtration and recrystallised from chloroform as needle crystals of m.p. 182.5-183.5° (lit. 179.5-180°)[49]. ν_{max} (Nujol) 3520 (OH); 1570 cm^{-1} (phenyl). ^1H n.m.r. ($CDCl_3$) δ 2.38, s, 2-CH; 2.63, s, 4-CH_3; 5.69, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 18.4, 6-CH_3; 26.3, 4-CH_3; 114.4, C2; 124.3, C5; 127.0, C6; 127.8, C3; 131.0, C4; 151.7, C1.

3,5,6-Tribromo-2,4-dimethyl-4-nitrocyclohexa-2,5-dienone (109)

Fuming nitric acid (5 ml; d 1.5) was added over 1½ min. to a stirred suspension of 3,5,6-tribromo-2,4-dimethylphenol (5 g) in acetic acid (40 ml) at c. 5°, and the mixture was stirred at 5° for 15 min. before adding a little water and cooling to deposit the nitrodienone (109) (4.12 g) isolated by filtration. The 4-nitrodienone (109) had m.p. 94-95° (lit. 97°)[50]. (Found C, 24.0; H, 1.8;

Br, 59.1; N, 3.3. $C_8H_6Br_3N_1O_3$ requires C, 23.8; H, 1.5; Br, 59.4; N, 3.5%). ν_{max} (Nujol) 1668 (C=O); 1630, 1592, (C=C); 1561 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.23, s, 2-CH_3, 4-CH_3. ^{13}C n.m.r. (CD_3COCD_3; -25°) δ 17.4, 2-CH_3; 26.2, 4-CH_3; 96.7, C4; 133.0, C6; 137.4, C2; 139.3, C3; 140.3, C5; 174.0, C1. λ_{max} ($CHCl_3$) 261, 297 nm (ε 13600, 2800).

Rearrangement of 3,5,6-Tribromo-2,4-dimethyl-4-nitrocyclohexa-2,5-dienone (109) in (D)Chloroform

A solution of the 4-nitrodienone (109) (500 mg) in $CDCl_3$ (5 ml) was stored in a darkened flask at 30° for 4 days. The solvent was removed under reduced pressure and the red material remaining, separated by silica gel Chromatotron plate to give 3,5,6-tribromo-2,4-dimethyl-4-nitratocyclohexa-2,5-dienone (110) (32 mg; 6%) which recrystallised from ether-petroleum ether to give crystals of m.p. 122-124° (dec.). (Found C, 23.1; H, 1.3; Br, 57.3; N, 3.1. $C_8H_6Br_3N_1O_4$ requires C, 22.9; H, 1.4; Br, 57.1; N, 3.3%). ν_{max} (Nujol) 1650 (C=O, ONO_2); 1582 (C=C); 1280, 835 cm^{-1} (ONO_2). ^1H n.m.r. ($CDCl_3$) δ 1.80, s, 4-CH_3; 2.20, s, 2-CH_3. λ_{max} ($CHCl_3$) 237, 265, 294 nm (ε 6320, 14500, 4790); and 3,5,6-tribromo-4-hydroxy-2,4-dimentylcyclohexa-2,5-dienone (81) (300 mg; 65%).

In later rearrangements one further compound was isolated; 3,5-dibromo-4,6-dimethyl-1,2-benzoquinone (111) (c. 4%) which recrystallised from dichloromethane-petroleum ether as bright red needle crystals with m.p. 128-131° (dec.).

(Found C, 32.7; H, 2.04; Br, 54.2. $C_8H_6Br_2O_2$ requires C, 32.7; H, 2.06; Br, 54.4%). ν_{max} (Nujol) 1695, 1657 (C=O); 1597, 1589, 1538 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 2.13, s, 6-CH_3; 2.58, s, 4-CH_3. λ_{max} ($CHCl_3$) 298 nm (ε 3890).

3,5,6-Tribromo-4-hydroxy-2,4-dimethylcyclohexa-2,5-dienone (81)

3,5,6-Tribromo-2,4-dimethyl-4-nitrocyclohexa-2,5-dienone (109) (4 g) was dissolved in acetic acid (20 ml) and heated at 60-65° for 2 hours. A little water was added to the solution which was then cooled to deposit the hydroxydienone (81) (1.85 g) isolated by filtration. A further crop of hydroxydienone (81) was obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (81) (total 2.44 g) from chloroform gave clear crystals of m.p. 176.5-178° (lit. 176°)[51]. ν_{max} (Nujol) 3420, 3270 (OH); 1660 (C=O); 1630, 1591 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 1.78, s, 4-CH_3; 2.15, s, 2-CH_3; 2.93, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 17.2, 2-CH_3; 30.0, 4-CH_3; 76.0, C4; 127.7, C6; 134.1, C2; 151.7, C3; 154.4, C5; 174.7, C1. λ_{max} ($CHCl_3$) 261, 298 nm (ε 14300, 3380).

Rearrangement of 2,3,5,6-Tetrachloro-4-methyl-4-nitrocyclohexa-2,5-dienone (87) in Acetic Acid

(a) Without added hydroquinone - A solution of the 4-nitrodienone (87) (300 mg) in acetic acid (5 ml) was stored in a darkened flask at 30° for 1 day. The solvent

was removed under reduced pressure and the crude product separated by silica gel Chromatotron plate to give 2,3,5,6-tetrachloro-4-methylphenol (90) (2 mg; 0.8%); 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) (43 mg; 19%) and 2,3,5,6-tetrachloro-4-hydroxy-4-methylcyclohexa-2,5-dienone (88) (205 mg; 76%).

(b) With added hydroquinone - A solution of the 4-nitrodienone (87) (300 mg) and hydroquinone (100 mg) in acetic acid (5 ml) was stored in a darkened flask at 30° for 1 day. The solvent was removed under reduced pressure and the crude product separated by silica gel Chromatotron plate to give 2,3,5,6-tetrachloro-4-methylphenol (90) (96 mg; 38%); 3,4,6-trichloro-5-methyl-1,2-benzoquinone (89) (10 mg; 4%) and 2,3,5,6-tetrachloro-4-hydroxy-4-methyl-cyclohexa-2,5-dienone (88) (64 mg; 24%).

Reactions of 2,3,5,6-Tetrabromo-4-methyl-4-nitrocycylhexa-2,5-dienone (112) with Sodium Acetate in Acetic Acid

(a) Anhydrous conditions - The tetrabromo-4-nitrodienone (112) (2 g) was added to a solution of anhydrous sodium acetate (1.5 g) in acetic acid (20 ml) and the suspension stirred in the dark at 20° for 7 days. Addition of water to the mixture gave a solid, identified as 2,3,5,6-tetrabromo-4-methylphenol (55) (1.716 g) isolated by filtration. Extraction of the filtrate with chloroform gave an oil (0.11 g), the components of which were separated on a silica gel Chromatotron plate to give:

(i) Further tetrabromophenol (55) (24 mg; total 96%)

(ii) 2,3,5-Tribromo-4-methyl-6-nitrophenol (58) (27 mg; 1.6%)

(iii) 2,3,5,6-Tetrabromo-4-hydroxy-4-methyl-cyclohexa-2,5-dienone (57) (33 mg; 1.8%).

(b) Added water - The tetrabromo-4-nitrodienone (112) (1.5 g) was added to a solution of sodium acetate (1.5 g) in acetic acid (1.5 ml) and water (7.5 ml) and the resulting mixture was stirred in the dark at 20° for 7 days. Addition of water to the mixture gave a solid, identified as the tetrabromo-4-nitrodienone (112) (1.529 g), isolated by filtration.

Reactions of 3,5,6-Tribromo-2,4-dimethyl-4-nitrocyclohexa-2,5-dienone (109) with Sodium Acetate in Acetic Acid

(a) Anhydrous conditions - The tribromo-4-nitrodienone (109) (1.5 g) was added to a solution of anhydrous sodium acetate (1.5 g) in acetic acid (20 ml) and the suspension stirred in the dark at 20° for 7 days. The crude product was isolated by addition of excess water and extraction using dichloromethane. The components of this mixture were separated by silica gel Chromotron plate followed by silica gel dry column chromotography using chloroform-carbon-tetrachloride as the eluting solvent mixture, giving:

(i) 2,3,5-Tribromo-6-hydroxy-4,6-dimethylcyclohexa-2,4-dienone (116) (464 mg; 33%) which recrystallised from ether-pet. ether as yellow crystals, m.p. 109-110°. (Found C, 25.7; H, 1.8; Br, 63.2. $C_8H_7Br_3O_2$ requires C, 25.6; H, 1.9; Br, 64.0%). ν_{max} (Nujol) 3490 (OH); 1680 (C=O); 1610 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 1.52, s, 6-CH_3; 2.43, s, 4-CH_3; 3.5, s, OH. λ_{max} ($CHCl_3$) 351 nm (ε 4380).

(ii) 3,5,6-Tribromo-4-hydroxy-2,4-dimethylcyclohexa-2,5-dienone (81) (203 mg; 15%)

(iii) The remaining product consisted of a complex mixture of polar oils (633 mg).

(b) Added water - The tribromo-4-nitrodienone (109) (1.5 g) was added to a solution of sodium acetate (1.5 g) in acetic acid (1.5 ml) and water (7.5 ml) and the resulting mixture was stirred in the dark at 20° for 7 days. Addition of water to the mixture gave a solid, identified as the tribromo-4-nitrodienone (109) (1.399 g), isolated by filtration.

Reactions of 3,5-Dibromo-2,4,6-trimethyl-4-nitrocyclohexa-2,5-dienone (95) with Sodium Acetate in Acetic Acid

(a) Anhydrous conditions - The dibromo-4-nitrodienone (95) (2 g) was added to a solution of anhydrous sodium acetate (1.5 g) in acetic acid (20 ml) and the solution stirred in the dark at 20° for 7 days. Addition of water to the mixture gave a solid, identified as 3,5-dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (1.09 g) isolated by filtration. Extraction of the filtrate with chloroform gave an oily mixture (779 mg), the components of which were separated on a silica gel Chromatotron plate to give:

(i) Further 6-hydroxycyclohexa-2,4-dienone (104) (373 mg; total 80%).

(ii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (141 mg; 8%).

(iii) 4-Acetoxymethyl-3,5-dibromo-6-hydroxy-2,6-dimethylcyclohexa-2,4-dienone (113) (158 mg; 7%) which

recrystallised from dichloromethane-petroleum ether as needle crystals of m.p. 130-132°. (Found C, 35.5; H, 3.6; Br, 42.8. $C_{11}H_{12}Br_2O_4$ requires C, 35.9; H, 3.3; Br, 43.4%). Mass spectrum (C.I., isobutane) MH^+ 367 (2 Br isotope pattern)). ν_{max} (Nujol) 3480 (OH); 1743 (acetate); 1666 (C=O); 1618 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 1.48, s, 2-CH_3; 2.10, s, $COCH_3$/6-CH_3; 2.87, s, OH; 5.32, s, 4-CH_2. λ_{max} ($CHCl_3$) 247, 326 nm (ε 6300, 5100).

(b) Added water - The dibromo-4-nitrodienone (95) (1 g) was added to a solution of sodium acetate (1 g) in acetic acid (1 ml) and water (5 ml) and the resulting mixture was stirred in the dark at 20° for 7 days. The crude product (900 mg) was isolated by addition of excess water and extraction using chloroform. The components of this mixture were separated on a silica gel Chromatotron plate to give:

(i) 2-Acetoxymethyl-3,5-dibromo-4,6-dimethylphenol (114) (26 mg; 2.5%), which recrystallised from petroleum ether with m.p. 95-96° (lit. 98-99°)[52]. (Found MH^+ 291 (2 Bromine isotope pattern) by mass spectroscopy (C.I.; ISOB)). ν_{max} (Nujol) 3250 (OH); 1701 (acetate); 1571 cm^{-1} (phenyl). ^1H n.m.r ($CDCl_3$) δ 2.13, s, CO-CH_3; 2.37, s, 6-CH_3; 2.62, s, 4-CH_3; 5.32, s, 2-CH_2; 8.6, s, OH.

(ii) 3,5-Dibromo-6-hydroxy-2,4,6-trimethylcyclohexa-2,4-dienone (104) (321 mg; 35%).

(iii) 3,5-Dibromo-4-hydroxy-2,4,6-trimethylcyclohexa-2,5-dienone (84) (155 mg; 17%).

(iv) 3,5-Dibromo-2,6-dimethyl-4-(nitromethyl)phenol (105) (194 mg; 19%).

(v) 3,5-Dibromo-4-cyano-2,6-dimethylphenol (115) (228 mg; 26%) which recrystallised from chloroform as white needles of m.p. 233-235° (dec.). (Found C, 35.2; H, 2.32; N, 4.4. $C_9H_7Br_2NO$ requires C, 35.4; H, 2.32; N, 4.6%). Mass spectrum (C.I.; isobutane) MH^+ 304 (2 Bromine isotope pattern). ν_{max} (Nujol) 3360 (OH); 2230 (CN); 1560 cm^{-1} (C=C). ^1H n.m.r. ($CDCl_3$) δ 2.38, s, 2-CH_3/6-CH_3.

Bromination of 2,4-dimethyl-6-nitrophenol (28c)

To 2,4-dimethyl-6-nitrophenol (28c) (2.0 g), iron dust (0.50 g) and chloroform (20 ml) in a darkened flask was added bromine (4.22 g) in chloroform (2 ml) over 5 minutes with slight heating. The mixture was refluxed 1½ hours before removing the solvent and eluting through a silica gel dry column using a mixture of 10% ether in petroleum ether. This afforded partial separating of the products with final separating by a silica gel Chromatotron plate giving 2,4-dimethyl-6-nitrophenol (28c) (1.371 g; 68%); 2,3,5-tribromo-4,6-dimethylphenol (0.530 g; 12%) and 3-bromo-2,4-dimethyl-6-nitrophenol (0.691 g; 23%) which was recrystallised from petroleum ether to give yellow crystals of m.p. 88-89°. (Found C, 38.9; H, 3.1; Br, 32.6; N, 5.5. $C_8H_8Br_1N_1O_3$ requires C, 39.1; H, 3.3; Br, 32.5; N, 5.7%). ν_{max} (Nujol) 3370 (OH); 1605, 1574 (phenyl); 1530 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.26, s, 2-CH_3; 2.38, s, 4-CH_3; 7.23, s, arom. proton; 8.70, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 16.1, 2-CH_3; 22.0, 4-CH_3; 111.7, C5; 127.9, C3; 130.9, C4; 134.1, C2; 143.2, C6; 146.3, C1.

3,5-Dibromo-2,4-dimethyl-6-nitrophenol

Powdered sodium nitrite (2.20 g) was added over ½ hour to a stirred suspension of 3,5,6-tribromo-2,4-dimethylphenol (10 g) in acetic acid (100 ml) at 20°. The mixture was stirred another hour before adding excess water (600 ml) and extracting with chloroform. Separation of the extract by silica gel dry column (eluted with 5% ether in pet. ether) and silica gel column chromatography gave 3,5,6-tribromo-2,4-dimethylphenol (0.8 g); 3,5-dibromo-2,4-dimethyl-6-nitrophenol (2.0 g) which was recrystallised from ether-petroleum ether as yellow needle crystals of m.p. 157-158.5° (lit. 158°)[52]. (Found C, 29.5; H, 2.2; Br, 49.1; N, 4.2. $C_8H_7Br_2N_1O_3$ requires C, 29.6; H, 2.2; Br, 49.2; N, 4.3%). ν_{max} (Nujol) 3450 (OH); 1579 (phenyl); 1525 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.42, s, 2-CH_3; 2.67, s, 4-CH_3; 8.65, s, OH. ^{13}C n.m.r. (CD_3COCD_3) δ 17.9, 4-CH_3; 24.5, 2-CH_3; 111.9, C5; 129.5, C3; 130.1, C2; 131.2, C4; 143.2, C6; 145.9, C1; and polar oils.

3,5-Dibromo-2,4-dimethyl-4,6-dinitrocyclohexa-2,5-dienone

Fuming nitric acid (0.25 ml; d 1.5) was added quickly to a stirred suspension of 3,5-dibromo-2,4-dimethyl-6-nitrophenol (0.27 g) in acetic acid (1 ml) at 20°, and the mixture was stirred 15 min. before being left to stand 15 min. A little water was added and the mixture cooled to precipitate nitrodienone (0.20 g) with m.p. 78-79° (dec.). (Found C, 25.9; H, 1.6; N, 6.9. $C_8H_6Br_2N_2O_5$ requires C, 26.0; H, 1.6; N, 7.6%). ν_{max} (Nujol) 1689 (C=O); 1613 (C=C); 1565, 1534 cm^{-1} (NO_2). ^1H n.m.r.

($CDCl_3$) δ 2.21, s, 2-CH_3; 2.25, s, 4-CH_3. ^{13}C n.m.r. (CD_3COCD_3; -25°) δ 16.5, 2-CH_3; 25.5, 4-CH_3; 95.0, C4; 131.6, C5; 138.2, C2; 140.0, C3; 164.3, C6; 171.3, C1. λ_{max} ($CHCl_3$) 256, 295 nm (ε 10600, 3200).

3,5-Dibromo-4-hydroxy-2,4-dimethyl-6-nitrocyclohexa-2,5-dienone

3,5-Dibromo-2,4-dimethyl-4,6-dinitrocyclohexa-2,5-dienone (0.20 g) was suspended in acetic acid (1 ml) and heated at 55-65° for 1 hour. A little water was added to the solution which was then cooled to deposit the hydroxydienone (0.06 g) isolated by filtration. A further crop of hydroxydienone was obtained by addition of water to the filtrate. Recrystallisation of the 4-hydroxydienone (total 0.08 g) from carbontetrachloride gave clear crystals of m.p. 132-132.5°. (Found C, 28.0; H, 2.3; Br, 46.8; N, 3.9. $C_8H_7Br_2N_1O_4$ requires C, 28.2; H, 2.1; Br, 46.9; N, 4.1%). ν_{max} (Nujol) 3410, 3300 (OH); 1663 (C=O); 1608 (C=C); 1548 cm^{-1} (NO_2). ^1H n.m.r ($CDCl_3$) δ 1.83, s, 4-CH_3; 2.16, s, 2-CH_3; 2.85, s, OH. ^{13}C n.m.r (CD_3COCD_3) δ 16.2, 2-CH_3; 29.3, 4-CH_3; 74.3, C4; 134.8, C2; 143.7, C5; 153.1, C3; 172.1, C1; signal for $\underline{C}$-NO_2 not observed. λ_{max} ($CHCl_3$) 255, 294 nm (ε 14800, 4900).

2,5,6-Tribromo-3,4-dihydroxytoluene

Bromine (5.2 ml) in chloroform (25 ml) was added dropwise over 1 hour to a stirred solution of 3,4-dihydroxytoluene in chloroform (30 ml) and ether (5 ml) at 20°. The solution was stirred 2 days in the dark before evaporating to give the crude 2,5,6-tribromo-3,4-dihydroxytoluene. Recrystallisation from chloroform gave white needle crystals of m.p. 158° (lit. 162-164°) ν_{max} (Nujol) 3420, 3200 cm^{-1} (OH). ^1H n.m.r. ($CDCl_3$) δ 2.61, s, CH_3; 5.78, s, OH.

4-methyl-2-nitrophenol

Nitric acid (13.2 ml; 1.42) in acetic acid (40 ml) was added dropwise to a stirred solution of 4-methyl-pehnol (20 g) dissolved in acetic acid (100 ml) at 0°. The solution was then stirred 15 min. at 0° and 15 min. at 20° before being poured into excess water (700 ml) and extracted with ether. Repeated tituration with hot pet. ether removed much of the oily impurity from the extract. Final purification was obtained by silica gel column chromatography followed by recrystallisation from pet. ether to give yellow crystals of m.p. 33-35° (lit. 33-34)[53]. ν_{max} (Nujol) 3230 (OH); 1629, 1584 (phenyl); 1538 cm^{-1} (NO_2). ^1H n.m.r. ($CDCl_3$) δ 2.34, s, CH_3; 6.89, 7.04, 7.27, 7.42, arom. protons; 7.83, s, OH.

APPENDIX I

CIS-2,5,6,6-TETRAMETHYL-2,3,4,5-TETRANITROCYCLOHEXA-3-ENONE (23)

Crystal unit cell data were obtained accurately using an Hilger and Watts four-circle diffractometer, and are shown below. The space group was determined unambiguously from systematic absences amongst hOl and OkO reflections. Zr filtered Mo-Kα radiation (λ(Mo-Kᾱ) 0.7107Å) and the θ/2θ scan techniques were used to collect reflection intensities out to a maximum Bragg angle θ of 21°. The cell parameters were determined by least-squares refinement, the setting angles of 12 accurately centred reflections being used. Absorption corrections were neither necessary nor warrented for this relatively weak data (μ(MoKα) = 1.52 cm^{-1}).

Crystal data for the cyclohexenone (23): $C_{10}H_{12}N_4O_9$, M 332.2, monoclinic, space-group $P2_1/c$, a 9.081(4), b 12.994(5), c 12.897(5)Å, β 112.98(4)°, z4, V 1401$Å^3$, Dc 1.57 g cm^{-1}, number of independent reflections measured 1135, number with $I > 3\sigma(I)$ 341, R factor 0.091, weighted R factor 10.4%.

All atoms were located in the structure solutions using direct methods and conventional difference Fourier synthesis. Full-matrix least-squares refinement of the structure solution was carried out with isotropic thermal parameters for all atoms and with methyl-hydrogen atoms included as rigid groups pivoting about their carbon atoms. Reflections were weighted according to the formula $4\ Fo^2/[\sigma^2(Fo) + 0.013\ F_o^2]$.

Computation was carried out using a Burroughs B6718 and a Prime 750 computer. The data processing program used was

HILGOUT[56], the refinement and geometry program used was SHELX[56] and the computed drawing of the structure was obtained using the program ORTEPII[56].

FRACTIONAL COORDINATES FOR NON-HYDROGEN ATOMS IN $C_{10}H_{12}N_4O_9$ (23)

Atom	x/a	y/b	z/c	Atom	x/a	y/b	z/c
C(1)	.117(6)	.144(4)	.531(4)	N(4)	.285(4)	.439(3)	.453(3)
C(2)	-.008(4)	.212(3)	.428(3)	N(5)	.343(4)	.302(2)	.669(3)
C(3)	.063(4)	.316(3)	.424(3)	O(1)	.067(3)	.091(2)	.579(2)
C(4)	.217(4)	.338(3)	.473(3)	O(21)	-.246(3)	.166(2)	.456(2)
C(5)	.343(4)	.263(3)	.551(3)	O(22)	-.133(3)	.306(2)	.529(2)
C(6)	.292(4)	.150(3)	.537(3)	O(31)	-.174(4)	.358(3)	.280(3)
C(7)	.310(5)	.105(3)	.436(3)	O(32)	-.024(3)	.480(2)	.366(2)
C(8)	.395(4)	.094(3)	.651(3)	O(41)	.286(4)	.454(2)	.369(3)
C(9)	-.073(4)	.149(3)	.319(3)	O(42)	.318(3)	.486(3)	.539(3)
C(10)	.501(4)	.285(3)	.547(3)	O(51)	.221(4)	.297(2)	.685(2)
N(2)	-.138(4)	.230(3)	.473(3)	O(52)	.478(4)	.175(2)	.246(2)
N(3)	-.053(5)	.391(3)	.350(3)				

TABLE 10

BOND LENGTHS FOR NON-HYDROGEN ATOMS IN $C_{10}H_{12}N_4O_9$(23)

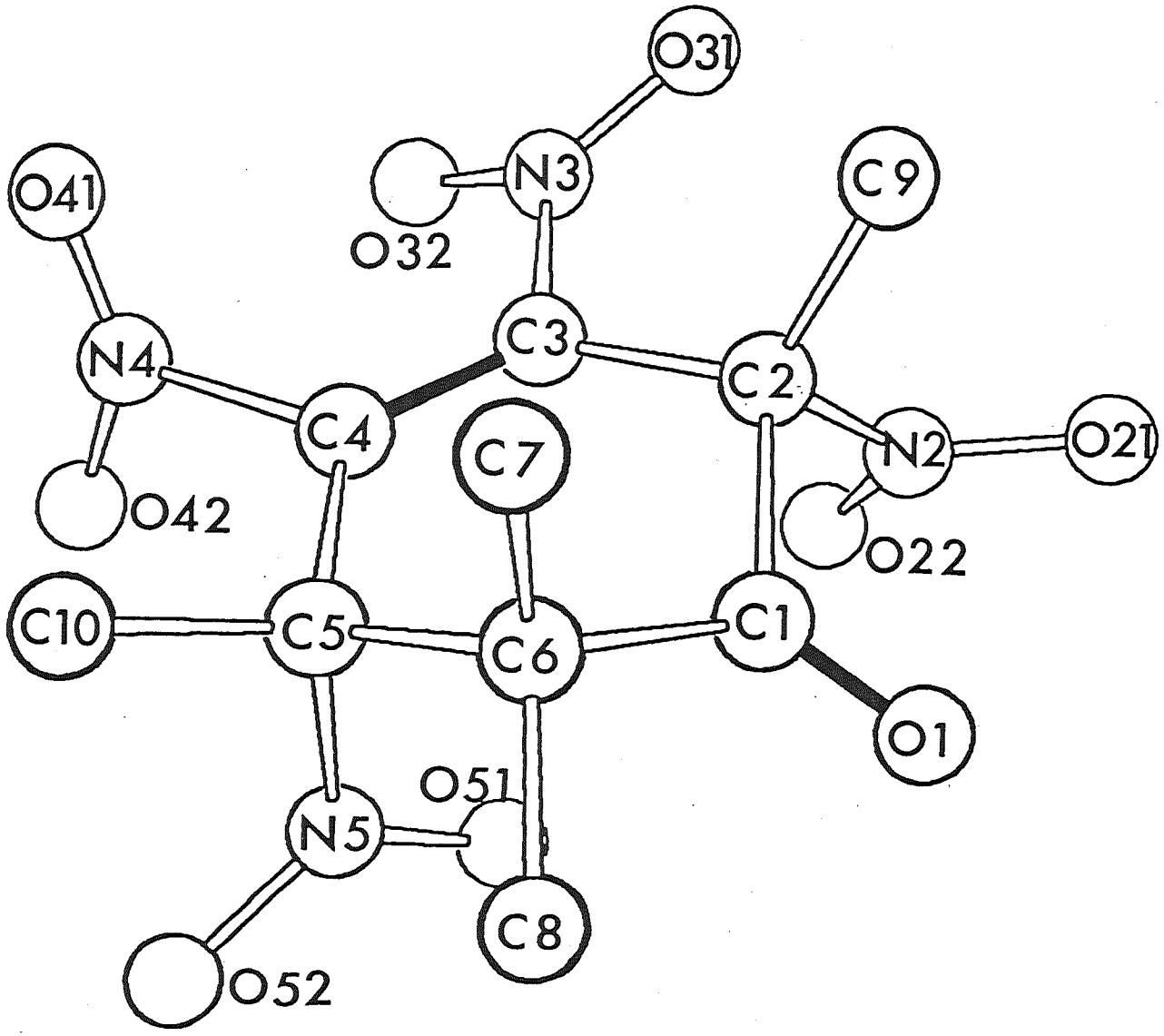
C1 - C2	1.63(5)Å	C5 - C10	1.48(4)Å
C1 - C6	1.56(5)	C6 - C7	1.50(4)
C1 - 01	1.13(5)	C6 - C8	1.58(4)
C2 - C3	1.50(4)	N2 - 021	1.24(4)
C2 - N2	1.53(4)	N2 - 022	1.21(4)
C3 - C4	1.32(4)	N3 - 031	1.19(4)
C3 - N3	1.48(4)	N3 - 032	1.19(4)
C4 - C5	1.54(4)	N4 - 041	1.09(4)
C4 - N4	1.52(4)	N4 - 042	1.20(3)
C5 - C6	1.53(4)	N5 - 051	1.21(4)
C5 - N5	1.60(4)	N5 - 052	1.27(4)

TABLE 11

BOND ANGLES FOR NON-HYDROGEN ATOMS IN $C_{10}H_{12}N_4O_9$ (23)

C6-C1-C2	113(4)°	C10-C5-C6	116(3)°
01-C1-C2	118(4)	C10-C5-N5	109(3)
01-C1-C6	128(4)	C5-C6-C1	108(3)
N2-C2-C1	100(3)	C7-C6-C1	113(3)
N2-C2-C3	106(3)	C7-C6-C5	110(3)
C9-C2-C1	111(3)	C8-C6-C1	105(3)
C9-C2-C3	118(3)	C8-C6-C5	107(3)
C9-C2-N2	111(3)	C8-C6-C7	114(3)
C4-C3-C2	124(3)	021-N2-C2	120(4)
N3-C3-C2	114(3)	022-N2-C2	120(4)
N3-C3-C4	121(3)	022-N2-021	120(4)
C5-C4-C3	124(4)	031-N3-C3	118(4)
N4-C4-C3	122(3)	032-N3-C3	118(4)
N4-C4-C5	114(3)	032-N3-031	124(4)
C6-C5-C4	115(3)	041-N4-C4	119(4)
N5-C5-C4	99(3)	042-N4-C4	105(3)
N5-C5-C6	108(3)	042-N4-041	137(4)
C10-C5-C4	110(3)	051-N5-C5	119(3)

TABLE 12



Computer drawing of cis-2,5,6,6-Tetramethyl-2,3,5,5-Tetranitrocyclohexa-3-enone (23).

APPENDIX II

(z)-3-BROMO-5-(BROMONITROMETHYLENE)FURAN-2(5H)-ONE (52)

Crystal unit cell data were obtained accurately from measurements on a Nicolet XRD P3 four-circle diffractometer, and are shown below. The space group was determined unambiguously from systematic absences amongst hOl and OkO reflections. Molybdenum X-radiation (λ(Mo K_α)0.71069Å) from a crystal monochromator and the $\theta/2\theta$ scan technique were used to collect reflection intensities out to a maximum Bragg angle θ of 25°. The crystal was yellow in colour and of approximate dimensions 0.04 by 0.11 by 0.98 mm. The cell parameters were determined by least-squares refinement, the setting angles of 25 accurately centred reflections ($25° < 2\theta < 35°$) being used. An absorption correction was applied empirically from azimuthal scans of selected reflections.

Crystal data for the furanone (52): $C_5HBr_2NO_4$, M298.9, monoclinic, space-group $P2_1/c$, a 7.361(1), b 6.678(1), c 16.774(3)Å, β 97.00(1)°, U 818.4Å^3, D_c 2.42 g cm^3, z 4; number of independent reflections measured 2049, number with $I > 3\sigma(I)$ 996; absorption corrections, maximum 1.26, minimum 0.35; R factor 0.057 (for 996 reflections); Rw 0.059.

The structure was solved by Patterson and difference-Fourier synthesis. Blocked-cascade least-squares refinements (SHELXTL)[54] were employed using reflection weighs $1/[\sigma^2(F)+0.000312(F^2)]$. The function minimized was $\Sigma\omega(|F_o| - |Fc|)^2$. Anomalous dispersion corrections were from Cromer and Liberman[55]. Final Fourier syntheses showed no

significant residual electron density and there were no abnormal discrepancies between observed and calculated structure factors.

The perspective drawing of the molecule (52) and its molecular dimensions are shown below.

FRACTIONAL COORDINATES FOR ATOMS IN $C_5HBr_2NO_4$ (52)

Atom	x/a	y/b	z/c	Atom	x/a	y/b	z/c
Br3	.7277(2)	.6371(2)	.11389(7)	C2	.389(2)	.570(2)	.1815(6)
Br6	-.0368(2)	.1155(2)	.17283(7)	C3	.516(1)	.493(2)	.1289(6)
O1	.2492(9)	.429(1)	.1784(4)	C4	.459(1)	.322(2)	.0970(5)
O2	.389(1)	.715(1)	.2208(5)	C5	.290(1)	.277(1)	.1292(5)
O61	.085(1)	-.176(1)	.0608(5)	C6	.170(1)	.124(1)	.1205(5)
O62	.340(1)	-.051(1)	.0378(5)	H4	.517(1)	.243(2)	.0596(5)
N6	.199(1)	-.047(1)	.0698(5)				

TABLE 13

BOND LENGTHS IN $C_5HBr_2NO_5$ (52)

O1-C2	1.39(1)Å	C5-O1	1.37(1)Å
C2-C3	1.45(2)	C5-C6	1.34(1)
C2-O2	1.17(1)	C6-Br6	1.85(1)
C3-C4	1.31(2)	C6-N6	1.45(1)
C3-Br3	1.88(1)	N6-O61	1.20(1)
C4-C5	1.45(2)	N6-O62	1.23(1)

TABLE 14

BOND ANGLES IN $C_5HBr_2NO_4$ (52)

C2-O1-C5	108.2(0.8)°	H4-C4-C5	126.8(0.5)°
O1-C2-C3	105.4(0.8)	C4-C5-C6	134.7(0.9)
O1-C2-O2	121.9(1.0)	O1-C5-C6	116.3(0.8)
O2-C2-C3	132.8(1.0)	C5-C6-Br6	122.6(0.7)
C2-C3-C4	111.0(0.9)	C5-C6-N6	121.1(0.9)
C2-C3-Br3	120.3(0.7)	N6-C6-Br6	116.3(0.7)
Br3-C3-C4	128.7(0.8)	C6-N6-061	119.3(0.9)
C3-C4-C5	106.3(0.9)	C6-N6-062	118.0(0.8)
C3-C4-H4	126.8(0.6)	061-N6-062	122.7(0.9)

TABLE 15

DEVIATIONS FROM PLANARITY (ALL ATOMS EQUALLY WEIGHTED, HYDROGEN EMITTED FROM CALCULATION)

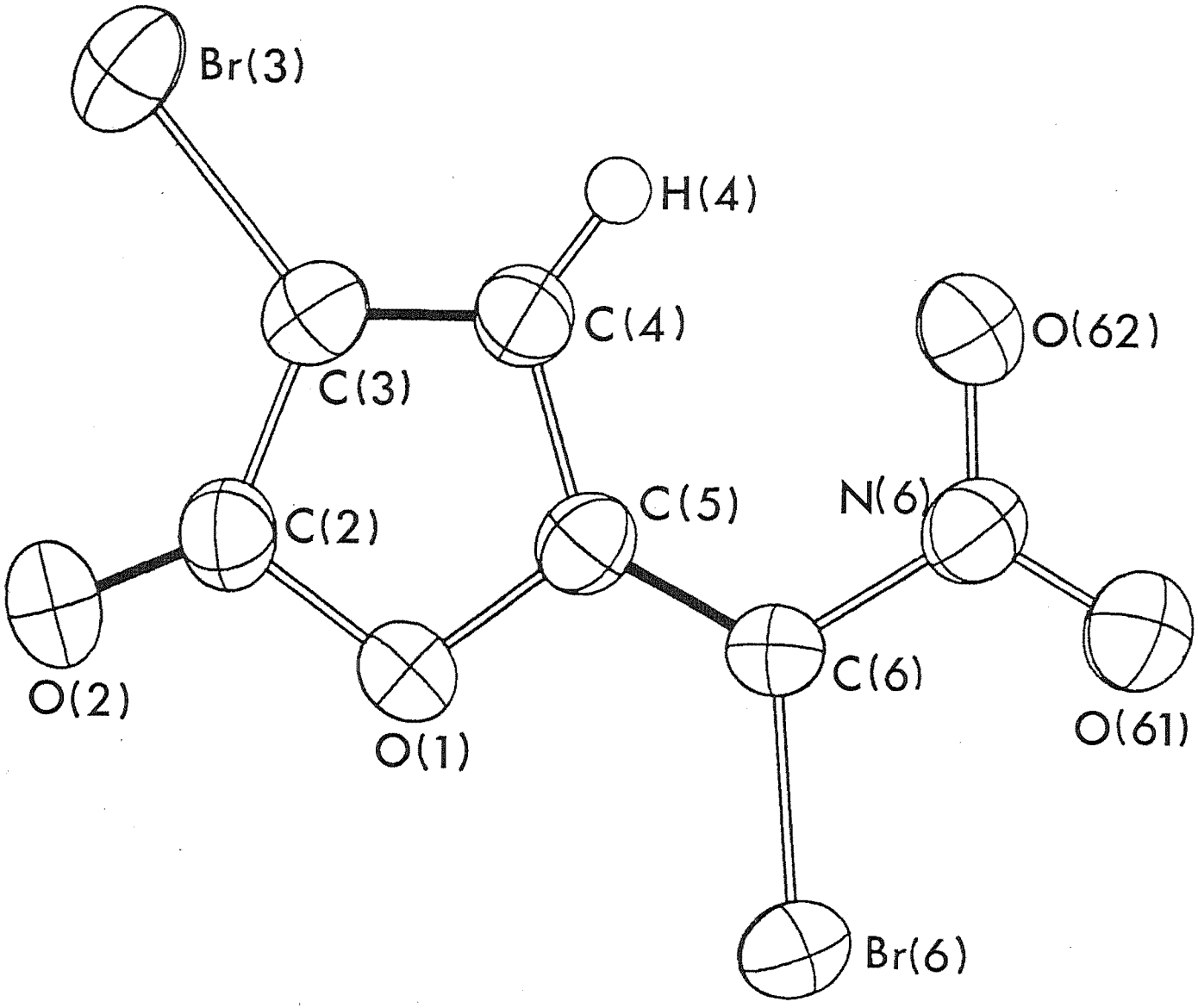
Br3	0.0032Å	C2	0.0021Å
Br6	.0277	C3	-.0066
O1	-.0196	C4	-.0329
O2	.0214	C5	-.0598
O61	-.0430	C6	-.0132
O62	.0617	H4	-.0055
N6	.0048		

TABLE 16

TORSION ANGLES IN $C_5HBr_2NO_4$ (52)

C5-O1-C2-O2	-178.9(0.9)°	Br3-C3-C4-C5	179.4(0.7)°
C2-O1-C5-C6	178.7(0.8)	C3-C4-C5-O1	2.0(1.0)
O62-N6-C6-Br6	-175.9(0.7)	H4-C4-C5-C6	1.1(1.4)
O1-C2-C3-C4	0.1(1.1)	C4-C5-C6-Br6	179.8(0.8)
Br3-C3-C4-H4	-0.6(1.2)	C2-O1-C5-C4	-2.0(0.9)
C2-C3-C4-C5	-1.2(1.1)	O61-N6-C6-C5	-177.0(0.9)
H4-C4-C5-O1	-178.0(0.4)	O1-C2-C3-Br3	179.5(0.6)
O1-C5-C6-N6	-179.9(0.7)	O2-C2-C3-C4	-179.9(1.1)
C5-O1-C2-C3	1.2(0.9)	C2-C3-C4-H4	178.8(0.5)
O61-N6-C6-Br6	4.2(1.1)	C3-C4-C5-C6	-178.9(1.0)
O62-N6-C6-C5	3.0(1.3)	O1-C5-C6-Br6	-1.1(1.1)
O2-C2-C3-Br3	-0.4(1.6)	C4-C5-C6-N6	1.0(1.6)

TABLE 17



Computer drawing of (z)-3-Bromo-5-(Bromonitromethylene)Furan-2(5H)-one(52)

APPENDIX III

2,3,6-TRIBROMO-4,5-DIHYDROXY-4-METHYLCYCLOHEXA-2,5-DIENONE(80)

Crystal unit cell data were obtained accurately from measurements on an Hilger and Watts four-circle diffractometer, and are shown below. The space group was determined unambiguously from systematic absences amongst hOl and OkO reflections. Zr filtered Mo-Kα radiation (λ(Mo-Kᾱ) 0.7107Å), and the θ/2θ scan technique were used to collect reflection intensities out to a maximum Bragg angle θ of 23°. The cell parameters were determined by least-squares refinement, the setting angles of 12 accurately centred reflections being used. An absorption correction was applied to the collected data.

Crystal data for the dienone(80): $C_7H_5Br_3O_3.H_2O$, M394.8, monoclinic, space-group $P2_1/_c$, a 7.278(2), b 16.520(4), c 9.057(2)Å, β 90.17(2), V 1089Å^3, Dc 2.41 g cm^3, z 4; number of independent reflections measured 1330, number with I>3σ(I) 822; absorption corrections maximum 9.95, minimum 4.46; R factor 0.0381 (for 822 reflections), Rw 0.0344.

All atoms were located in the structure solution using direct methods and conventional difference Fourier syntheses. Full-matrix least-squares refinement of the structure solution was carried out with anisotropic thermal parameters for all non-hydrogen atoms and with methyl-hydrogen atoms included as rigid groups pivoting about their carbon atoms. Reflections were weighted according to the formula $1.212/(\text{Sigma}^2(F) + 0.000473F^2)$.

Computation was carried out using a Burroughs B6718 and a Prime 750 computer. The data processing program used was (HILGOUT)[56], the refinement and geometry program used was SHELX[56] and the computed drawing of the structure was obtained using the program ORTEPII[56].

The perspective drawing of the molecule (80) and its molecular dimensions are shown below.

FRACTIONAL COORDINATES FOR NON-(METHYL-HYDROGEN) ATOMS

IN $C_7H_5Br_3O_3.H_2O$(80)

Atom	x/a	y/b	z/c	Atom	x/a	y/b	z/c
Br2	.8794(2)	.1347(1)	.1889(2)	C3	.848(2)	.3021(6)	.160(1)
Br5	.4792(2)	.4869(1)	.2853(2)	C4	.776(2)	.3871(6)	.190(1)
Br6	.3196(2)	.3192(1)	.4552(2)	C5	.595(2)	.3856(6)	.270(1)
O1	.561(1)	.1797(4)	.3838(9)	C6	.528(2)	.3200(6)	.335(1)
O3	.989(1)	.2955(4)	.070(1)	C7	.918(2)	.4326(7)	.281(1)
O4	.762(1)	.4301(4)	.0530(9)	H91	.225(14)	.0443(9)	.463(9)
O9	.220(1)	.1015(4)	.481(1)	H92	.181(16)	.125(4)	.390(6)
C1	.620(2)	.2405(6)	.318(1)	H3	1.075(11)	.336(5)	.040(12)
C2	.774(2)	.2369(6)	.223(1)	H4	.690(14)	.400(6)	-.017(10)

TABLE 18

BOND LENGTHS IN $C_7H_5Br_3O_3.H_2O$(80)

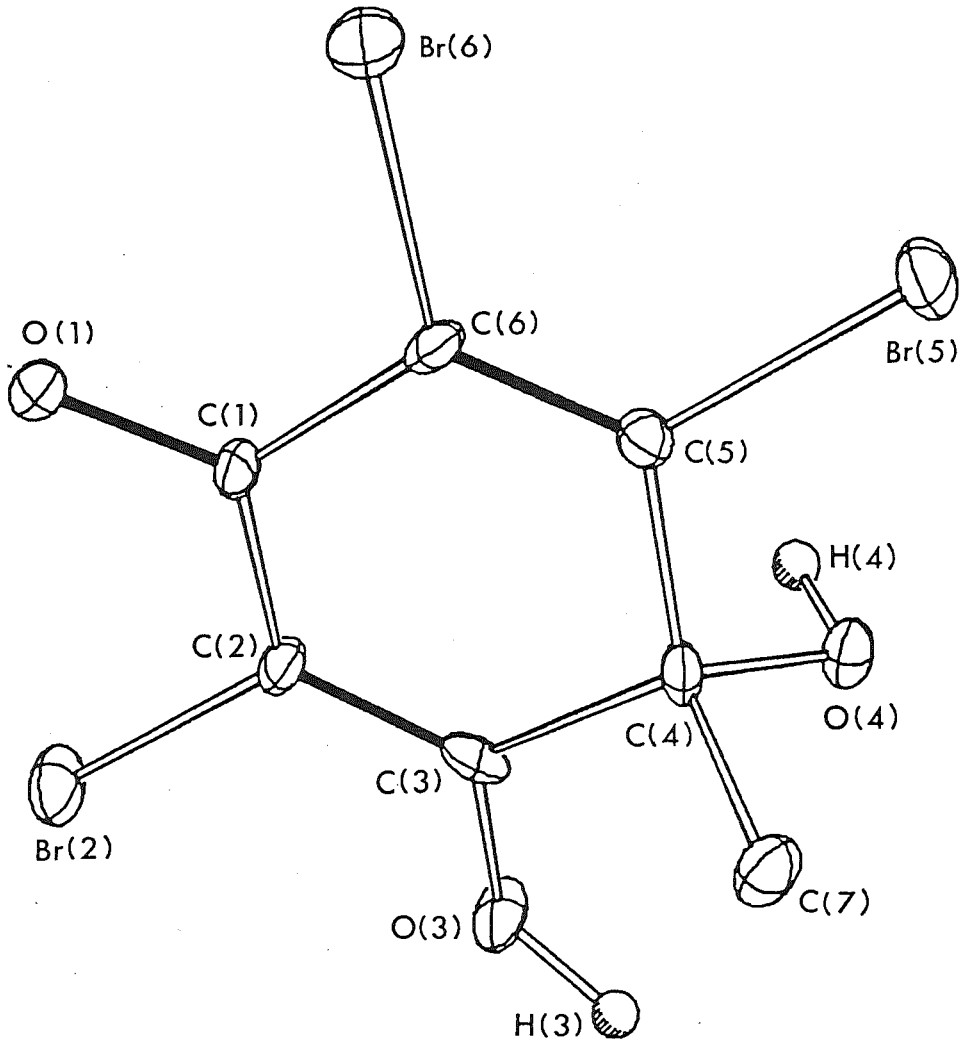
C1 - C2	1.42(2)Å	C4 - O4	1.43(1)Å
C1 - C6	1.48(2)	C5 - C6	1.33(1)
C1 - O1	1.25(1)	C5 - Br5	1.88(1)
C2 - C3	1.34(2)	C6 - Br6	1.87(1)
C2 - Br2	1.88(1)	O3 - H3	0.96
C3 - C4	1.53(1)	O4 - H4	0.96
C3 - O3	1.32(1)	H4 - O1	1.85
C4 - C5	1.50(2)	H3 - O9	1.57
C4 - C7	1.52(2)	O4 - H91	1.90

TABLE 19

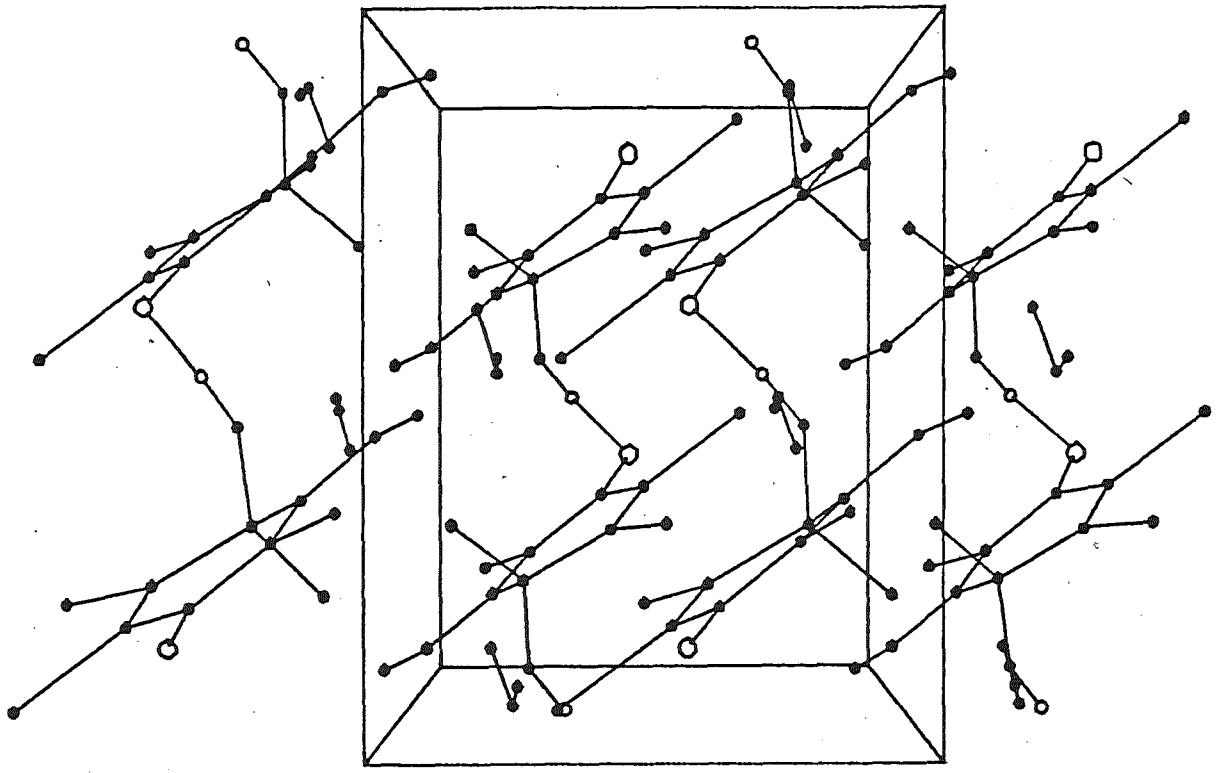
BOND ANGLES IN $C_7H_5Br_3O_3.H_2O$(80)

C2-C1-C6	117.5(0.9)°	C5-C4-C7	110.0(0.9)°
O1-C1-C2	122.1(1.0)	O4-C4-C5	111.5(1.0)
O1-C1-C6	120.4(1.1)	O4-C4-C7	105.8(0.8)
C1-C2-C3	123.3(1.0)	C4-C5-C6	123.5(1.0)
C1-C2-Br2	117.6(0.7)	C4-C5-Br5	114.5(0.7)
C3-C2-Br2	119.1(0.8)	Br5-C5-C6	121.8(0.9)
C2-C3-C4	121.6(1.0)	C1-C6-C5	120.4(1.0)
C2-C3-O3	121.1(1.0)	C5-C6-Br6	124.5(0.9)
O3-C3-C4	117.3(1.0)	C1-C6-Br6	115.1(0.7)
C3-C4-C5	112.1(0.9)	C3-O3-H3	128.7(6.3)
C3-C4-C7	108.4(1.0)	C4-O4-H4	110.4(6.7)
C3-C4-O4	108.9(0.9)	H91-O9-H92	105.7(0.5)

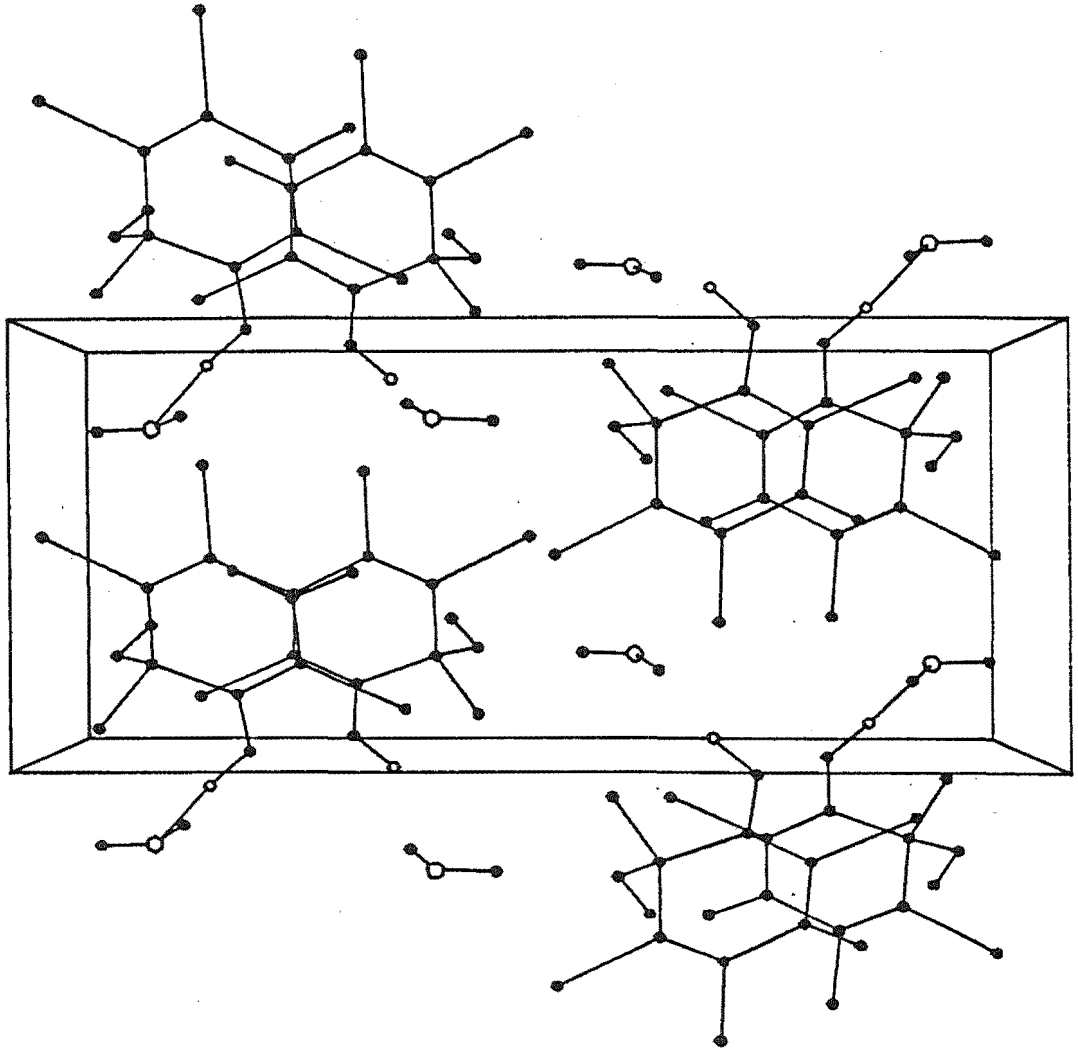
TABLE 20



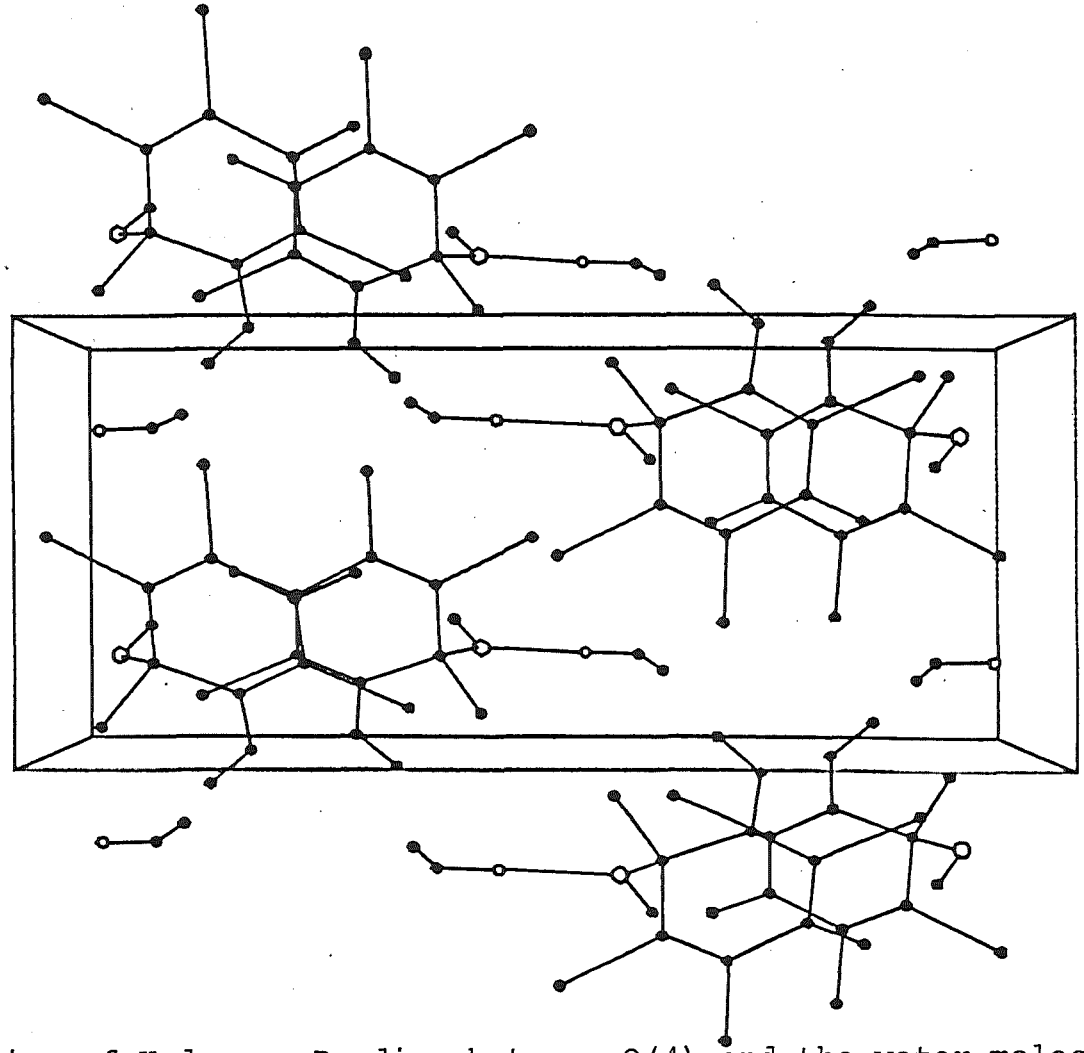
Computer drawing of 2,3,6-Tribromo-4,5-Dihydroxy-4-Methylcyclohexa-2,5-dienone (80)



Computer drawing of Hydrogen Bonding between O(1) and H(4).



Computer drawing of Hydrogen Bonding between H(3) and the water molecules oxygen atom (0(9)).



Computer drawing of Hydrogen Bonding between O(4) and the water molecules hydrogen atom (H(91)).

APPENDIX IV

3,4-DIBROMO-5-METHYL-5-(2´-NITROETHAN-1´-ONE)-2(5H)-FURANONE(86)

Crystal unit cell data were obtained accurately from measurment on a Nicolet XRD P3 four-circle diffractometer, and are shown below. The space group was determined unambiguously from systematic absences amongst hOl and OkO reflections. Molybdenum X-radiation (λ(Mo Kα)0.71069Å) from a crystal monochromator and the $\theta/2\theta$ scan technique were used to collect reflection intensities out to a maximum Bragg angle θ of 26°. The cell parameters were determined by least-squares refinement, the setting angles of 25 accurately centred reflections ($25° < 2\theta < 35°$) being used. An absorption correction was applied empirically from azimuthal scans of selected reflections.

Crystal data for the furanone(86): $C_7H_5Br_2NO_4$, M326.9, monoclinic, space-group $P2_1/c$, a 8.250(2), b 16.620(4), c 8.148(2), β 108.09(2), V 1062 Å^3, Dc 2.04 g cm^3, z 4; number of independent reflections measured 2102, number with $I > 3\sigma(I)$ 1511; Rw 0.0347, R 0.0372.

The structure was solved by Patterson and difference Fourier syntheses. Block-cascade least-squares refinements (SHELXTL)[54] were employed using reflection weights $1/[\sigma^2(F)+0.001(F^2)]$. The function minimized was $\Sigma\ \omega(|Fo| - |Fc|)^2$. Anomalous dispersion corrections were from Cromer and Liberman[55]. Final Fourier syntheses showed no significant residual electron density and there were no abnormal discrepancies between observed and calculated structure factors.

The perspective drawing of the molecule (86) and its molecular dimensions are shown.

FRACTIONAL COORDINATES FOR NON-(METHYL-HYDROGEN) ATOMS IN

$C_7H_5Br_2NO_4$ (86)

Atom	x/a	y/b	z/c	Atom	x/a	y/b	z/c
Br3	.7918(1)	-.0801(1)	.3219(1)	C3	.7066(6)	.0241(3)	.2818(7)
Br4	.7043(1)	.0623(1)	.6236(1)	C4	.6748(6)	.0754(3)	.3905(6)
O1	.5996(4)	.1351(2)	.1203(4)	C5	.6066(6)	.1533(3)	.2963(6)
O2	.6716(5)	.0342(2)	-.0245(4)	C6	.4265(7)	.1717(3)	.3027(7)
O6	.4064(5)	.1971(3)	.4324(5)	C7	.2807(7)	.1557(3)	.1393(7)
O71	.0795(6)	.2442(3)	.1816(7)	C8	.7223(8)	.2260(3)	.3612(8)
O72	.0320(6)	.1178(3)	.1919(8)	H71	.2792(60)	.1951(23)	.0365(42)
N7	.1175(6)	.1744(4)	.1721(7)	H72	.2730(72)	.0947(11)	.0998(73)
C2	.6621(6)	.0601(3)	.1079(6)				

TABLE 21

BOND LENGTHS IN $C_7H_5Br_2NO_4$ (86)

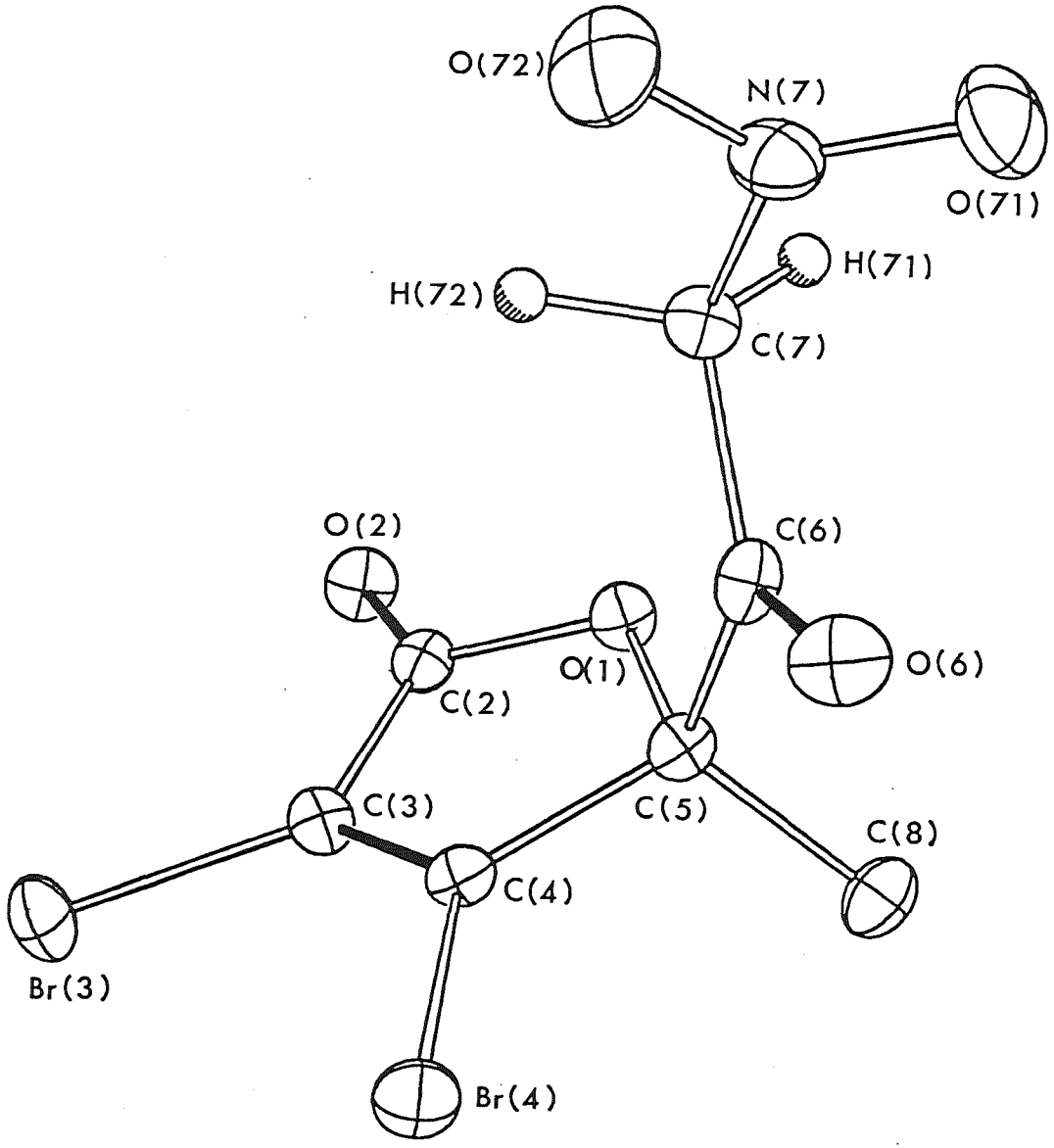
O1 - C2	1.363(6)Å	C5 - C6	1.534(8)Å
C2 - O2	1.188(7)	C6 - O6	1.196(7)
C2 - C3	1.475(7)	C6 - C7	1.515(7)
C3 - Br3	1.860(5)	C7 - H71	1.060(38)
C3 - C4	1.313(8)	C7 - H72	1.060(26)
C4 - Br4	1.851(5)	C7 - N7	1.485(8)
C4 - C5	1.521(7)	N7 - O71	1.209(8)
C5 - C8	1.530(7)	N7 - O72	1.217(8)

TABLE 22

BOND ANGLES IN $C_7H_5Br_2NO_4$ (86)

C5-O1-C2	111.3(4)°	C6-C5-C8	109.7(4)°
O1-C2-C3	106.7(4)	O1-C5-C8	109.7(5)
O1-C2-O2	122.2(4)	C4-C5-C8	113.9(4)
O2-C2-C3	131.2(5)	C4-C5-C6	111.3(4)
C2-C3-C4	110.0(4)	C5-C6-O6	120.1(4)
C2-C3-Br3	121.0(4)	O6-C6-C7	123.3(5)
Br3-C3-C4	129.0(4)	C5-C6-C7	116.6(5)
C3-C4-C5	109.4(4)	C6-C7-N7	108.5(5)
C3-C4-Br4	128.8(4)	C7-N7-O71	118.7(5)
Br4-C4-C5	121.9(4)	C7-N7-O72	117.2(5)
O1-C5-C4	102.5(4)	O71-N7-O72	124.1(6)
O1-C5-C6	109.5(4)		

TABLE 23



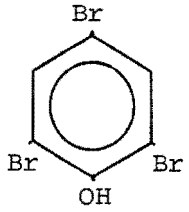
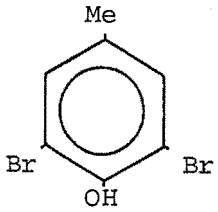
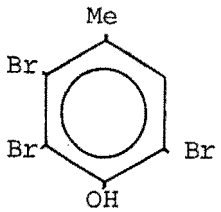
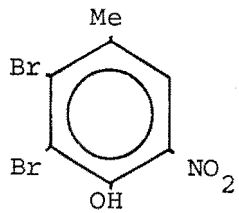
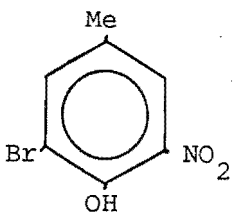
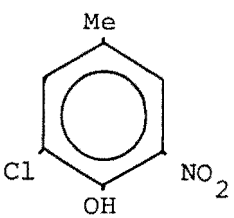
Computer drawing of 3,4-Dibromo-5-Methyl-5-(2´-Nitroethan-1´-one)-2(5H)-Furanone (86).

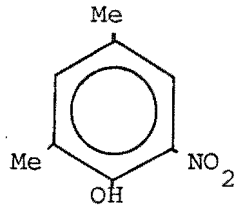
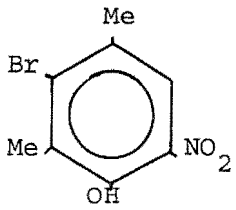
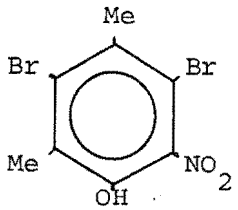
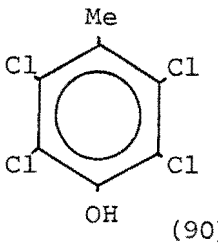
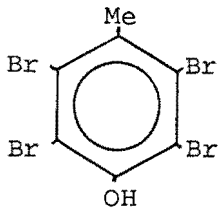
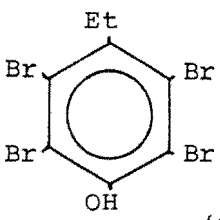
APPENDIX 5

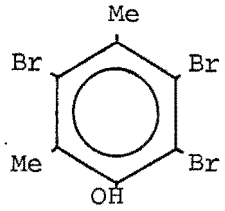
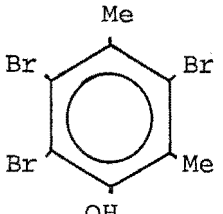
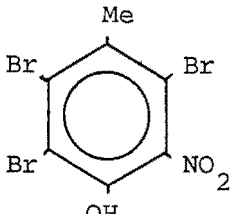
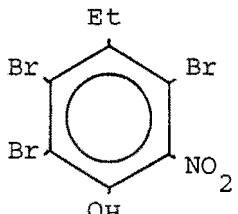
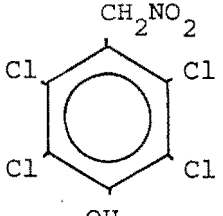
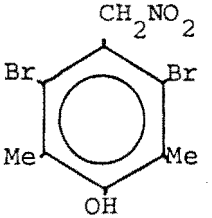
SPECTROSCOPIC DATA

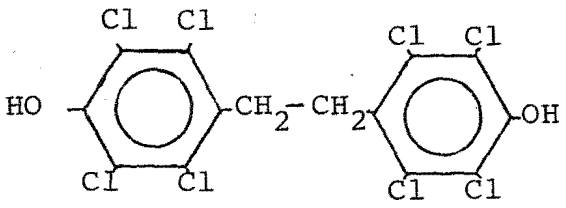
In order to appreciate the trends present in the spectroscopic data given in the experimental section (Chapter 8), the data is reproduced here in tabular form. Note that the numbering system for the compounds is different to that in the rest of this thesis. Compounds containing a six carbon ring system will be numbered from the carbon atom closest to the bottom of the tables and runs anti-clockwise. It is hoped that this will lead to a clearer view of the spectroscopic trends.

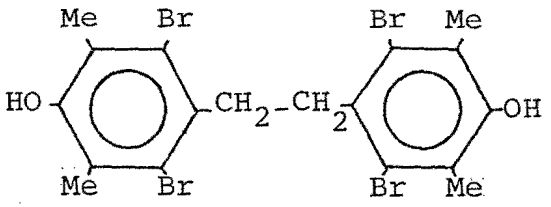
All ^{13}C n.m.r. spectra were run in (D^6)-acetone, most ^{1}H n.m.r. spectra in (D)-chloroform, infra-red spectra as nujol mulls and untraviolet spectra in chloroform. Exceptions to these are stated on the relevant tables below.

			 (50)	 (31)	 (32)	 (28b)	 (28a)
^{13}C n.m.r.	4-Me	-	19.8	23.9	22.1	19.9	20.0
	2-Me	-	-	-	-	-	-
	1	151.4	149.2	150.8	149.3	150.3	149.4
	2	112.3	111.2	115.3	115.6	113.1	124.1
	3	135.1	133.0	127.0	130.3	142.1	138.8
	4	112.5	133.4	133.5	135.9	131.7	130.9
	5	135.1	133.0	133.1	123.0	124.9	124.1
	6	112.3	111.2	109.9	-	135.0	135.2
^{1}H n.m.r.	3H	7.63	7.20	-	-	7.58	7.52
	5H	7.63	7.20	7.33	8.00	7.77	7.82
	4-Me	-	2.23	2.38	2.51	2.33	2.35
	2-Me	-	-	-	-	-	-
	OH	5.83	5.67	5.83	11.5	10.96	10.85
I.R.	Hydroxyl	3400	3550	3470	3200	3160	3220
	Phenyl	1557	1562	1578, 1553	1610	1620	1622
	Nitro	-	-	-	1531	1543	1550
Melting point		88-89°	45.5-47.5°	97-98°	120-122°	65-66.5°	62-63°

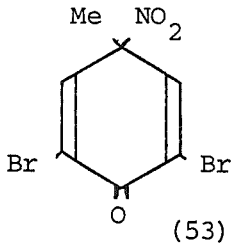
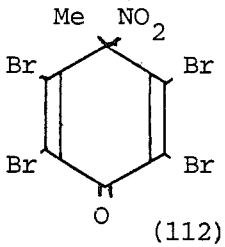
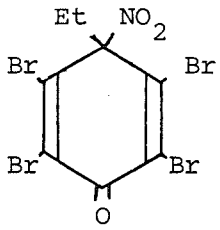
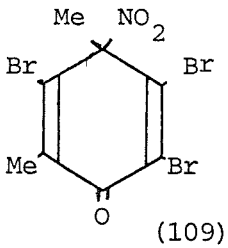
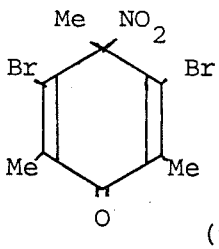
		 (28c)			 (90)	 (55)	 (61)
^{13}C n.m.r.	4-Me/Et	20.1	22.0	17.9	19.1	(with Cr(acac)$_3$) –	12.7, 34.6
	2-Me	15.6	16.1	24.5	–	–	–
	1	152.2	146.3	145.9	149.8	151.8	151.8
	2	129.8	134.1	130.1	120.5	114.9	115.1
	3	140.1	127.9	129.5	128.2	127.3	126.8
	4	130.1	130.9	131.2	132.4	132.8	137.9
	5	122.5	111.7	111.9	128.2	127.3	126.8
	6	–	143.2	143.2	120.5	114.9	115.1
^{1}H n.m.r.	3H	7.20	–	–	–	–	–
	5H	7.64	7.23	–	–	–	–
	4-Me/Et	2.29	2.38	2.67	2.48	2.73	1.14, 3.16
	2-Me	2.29	2.26	2.42	–	–	–
	OH	10.73	8.70	8.65	5.95	6.08	6.03
I.R.	Hydroxyl	3220	3370	3450	3420	3430	3420
	Phenyl	1626, 1599	1605, 1574	1579	1572, 1556	1555, 1530	1551, 1523
	Nitro	1545	1530	1525	–	–	–
Melting Point		71.5-73°	88-89°	157-158.5°	191-193°	198-199°	107-108°

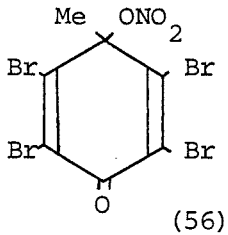
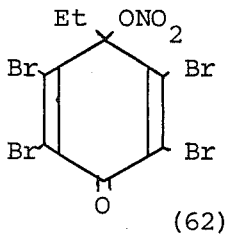
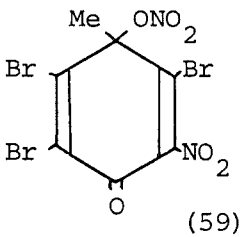
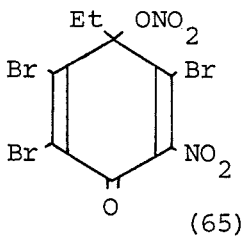
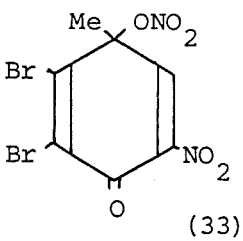
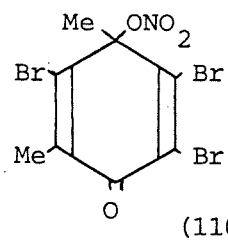
			 (103)	 (58)	 (64)	 (102)	 (105)
^{13}C n.m.r.	4-Me/Et	26.3	25.2	25.7	12.6, 32.9	74.1	81.6
	2-Me	18.4	17.8	-	-	-	17.6
	1	151.7	152.3	146.0	146.2	164.0	155.9
	2	127.0	125.6	114.3	113.9	119.7	122.4
	3	124.3	125.4	129.9	129.4	133.4	126.1
	4	131.0	129.1	132.8	137.8	151.6	128.2
	5	127.8	125.4	116.9	117.4	133.4	126.1
	6	114.4	125.6	-	-	119.7	122.4
^{1}H n.m.r.	4-Me/Et	2.63	2.60	2.68	1.17, 3.15	5.85	5.97
	2-Me	2.38	2.36	-	-	-	3.37
	OH	5.69	-	6.67	6.65	5.0	5.22
I.R.	Hydroxyl	3520	3360	3440	3410	3430	3530
	Phenyl	1570	1570	1580	1584	1569, 1557	-
	Nitro	-	-	1540	1535	1546	1552
Melting Point		182.5-183.5°	155-157°	159-160°	127-128°	135-136°	136-137°

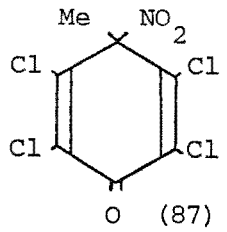




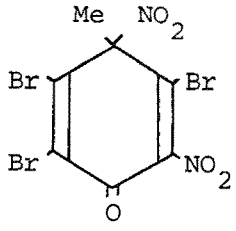
	91	106
^{1}H n.m.r. Me	-	2.36
(CD_3COCD_3) CH_2	-	3.40
I.R.		
Hydroxy	3520	3450
Phenyl	1562, 1544	1561
Melting point	176 - 178°	293 - 295°

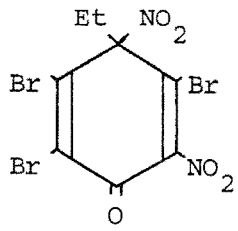
		 (53)	 (112)		 (109)	 (95)
^{13}C n.m.r. (at -25°)	4-Me/Et			7.3-32.6	26.2	26.2
	2-Me			-	17.4	16.8
	1			-	174.0	179.3
	2			132.6	137.4	137.1
	3			140.0	139.3	139.6
	4			101.4	96.7	95.3
	5			140.0	140.3	139.6
	6			132.6	133.0	137.1
^{1}H n.m.r.	4-Me/Et	2.00	2.25	0.75, 2.79	2.23	2.15
	2-Me	-	-	-	2.23	2.15
	H3/H5	7.58	-	-	-	-
I.R.	Carbonyl	1690	1682	1690	1668	1665
	C=C	1601	1607	1602	1630, 1592	1624
	Nitro	1561	1579, 1563	1573, 1563	1561	1566
U.V.	nm		275, 307	274, 310	261, 297	253, 289
	(ε)		10300, 1980	15000, 2800	13600, 2800	17200, 3700

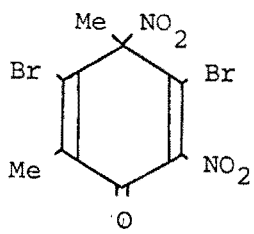
		 (56)	 (62)	 (59)	 (65)	 (33)	 (110)
^{13}C n.m.r.	4-Me/Et	26.6	6.5, 31.9	26.0	6.5, 32.3	25.2	
	2-Me	-	-	-	-	-	
	1	-	169.6	166.6	166.7	-	
	2	129.0	129.8	129.4	130.1	129.7	
	3	146.4	145.3	147.6	146.9	147.6	———
	4	87.4	91.3	85.8	89.3	82.0	
	5	146.4	145.3	138.2	137.5	142.6	
	6	129.0	129.8	-	-	-	
^{1}H n.m.r.	4-Me/Et	1.85	0.70, 2.16	1.92	0.80, 2.22	1.85	1.80
	2-Me	-	-	-	-	-	2.20
	5H	-	-	-	-	7.73	-
I.R.	Carbonyl	1675	1683	1688	1687	1701	1650
	Nitrate	1657, 1276 824	1652, 1273 831	1661, 1278 825	1658, 1274 830	1661, 1279 831	1650, 1280 835
	C=C	1599, 1572	1598, 1571	1572	1570	-	1582
	Nitro	-	-	1549	1550	1546	-
U.V.	nm	276, 308	276, 305	263, 305	263.5, 307	299	237, 265, 294
	(ε)	12900, 2900	16300, 3230	14300, 4540	16200, 4920	5500	6320, 14500, 4790
Melting point		153-153.5°	118-119°	174-175°	140-141°	101-103°	122-124°



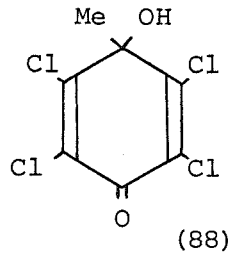
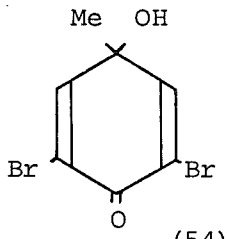
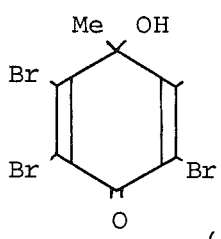
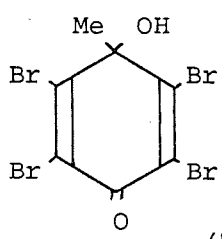
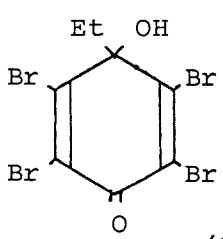
(87)

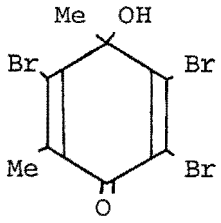
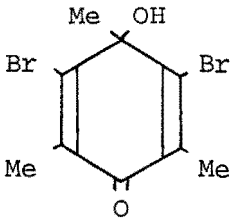
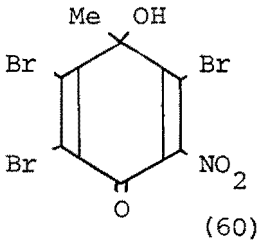
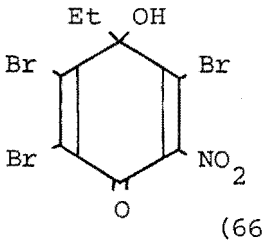
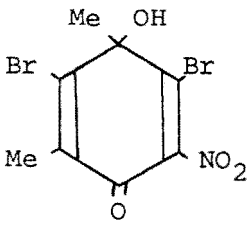


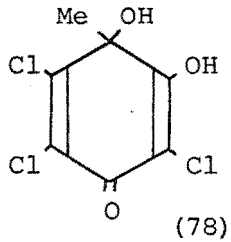
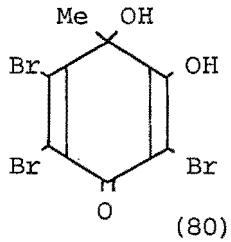
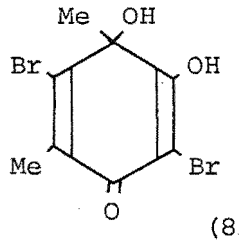
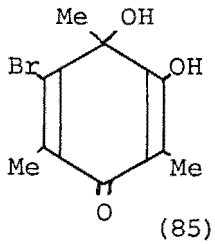


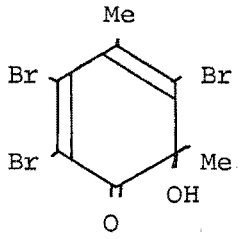


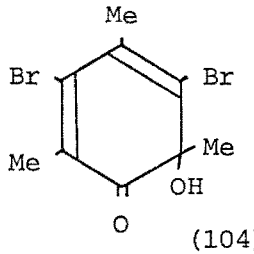
^{13}C n.m.r.	4-Me/Et	(with Cr(acac)$_3$) 23.6	25.6	7.2, 32.7	25.5
	2-Me	-	-	-	16.5
	1	169.4	166.5	166.4	171.3
	2	134.9	132.4	132.0	138.2
	3	143.5	141.5	140.9	140.0
	4	95.1	96.3	99.7	95.0
	5	143.5	131.6	132.9	131.6
	6	134.9	-	151.7	164.3
^{1}H n.m.r	4-Me/Et	2.25	2.33	0.83, 2.82	2.25
	2-Me	-	-	-	2.21
	H3/H5	-	-	-	-
I.R.	Carbonyl	1680	1679	1692	1689
	C=C	1614	-	1642	1613
	Nitro	1576	1574, 1547	1575, 1550	1565, 1534
U.V.	nm	256, 290	262, 306	263, 309	256, 295
	(ε)	12600, 2300	10300, 3380	9050, 3000	10600, 3200

	 (88)	 (54)	 (49)	 (57)	 (63)
^{13}C n.m.r. 4-Me/Et	24.7	26.4	27.9	27.7	7.6, 35.6
1	167.6	172.4	171.2	167.3	170.0
2	127.2	120.2	125.7	123.5	126.9
3	153.0	154.7	157.0	152.7	153.8
4	73.0	72.0	74.8	75.8	82.3
5	153.0	154.7	154.2	152.7	153.8
6	127.2	120.2	119.2	123.5	126.9
^{1}H n.m.r. 4-Me/Et	1.83	1.55	1.65	1.83	0.62, 2.21
5H	-	7.37	7.53	-	-
OH	3.12	3.3	2.8	2.70	3.10
I.R. Hydroxyl	3410, 3330 3250	3470	3470	3400, 3260	3460
Carbonyl	1681	1676, 1669	1663	1675, 1668	1666
C=C	1613, 1589	1601, 1591	1620	1599, 1572	1601, 1595 1575, 1563
U.V. nm	256, 298	258	265, 300	272, 309	272, 309
(ε)	14100, 2400	9350	10600, 2100	11600, 3200	12440, 2410
Melting point	168-169.5°	133.5-135°	127-9°	209-212°	139-141°

				 (60)	 (66)	
^{13}C n.m.r.	4-Me/Et	30.0	30.0	29.3	7.4, 35.4	29.3
	2-Me	17.2	16.6	-	-	16.2
	1	174.7	180.3	167.2	167.4	172.1
	2	134.1	134.7	126.0	126.9	134.8
	3	151.7	151.4	156.4	155.5	153.1
	4	76.0	73.6	76.6	80.5	74.3
	5	154.4	151.4	144.9	143.8	143.7
	6	127.7	134.7	-	-	-
^{1}H n.m.r.	4-Me/Et	1.78	1.72	1.87	0.71, 2.27	1.83
	2-Me	2.15	2.10	-	-	2.16
	OH	2.93	-	3.08	3.13	2.85
IR	Hydroxyl	3420, 3270	3430, 3270	3470	3540	3410, 3300
	Carbonyl	1660	1639	1669	1677	1663
	C=C	1603, 1591	-	1570	1645, 1570	1608
	Nitro	-	-	1540	1543	1548
U.V.	nm	261, 298	254, 291	261, 306	262, 307	255, 294
	(ε)	14300 3380	18300 4600	13800 3990	14800	14800 4900
Melting point		176.5-178°	130.5-131.5°	157-9°	140-2°	132-132.5°

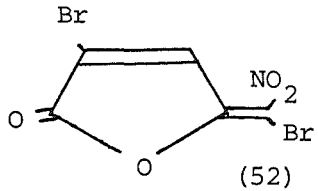
		 (78)	 (80)	 (82)	 (85)
^{13}C n.m.r.	4-Me	23.5	24.6	28.3	
	2-Me	-	-	17.0	
	1	167.5	168.2	172.4	
	2	126.4	122.6	134.0	———
	3	147.6	146.2	146.8	
	4	70.8	71.8	74.0	
	5	168.8	169.3	177.7	
	6	103.8	93.0	98.9	
^{1}H n.m.r. (CD_3COCD_3)	4-Me	1.76	1.75	1.68	1.76
	2-Me	-	-	2.04	2.00
	6-Me	-	-	-	1.62
	OH	5.48	4.90	-	3.73, 5.10
I.R.	OH	3530, 3470 3310	3560, 3480 3320	3250, 3160	3270
	C=O	1616, 1602	1608, 1598	(1652, 1624 1608)	(1663, 1620 1601, 1580)
	C=C	1569	1562		
U.V. (Dioxan)	nm	220, 250, 308	218, 259, 313	217, 250, 303	216, 247, 299
	(ε)	7940, 11200 2520	1400, 16100 3630	6770, 14200 3470	6180, 14800 3690
Melting point		149-150°	154-155° 173-175°	191-192°	222-223°



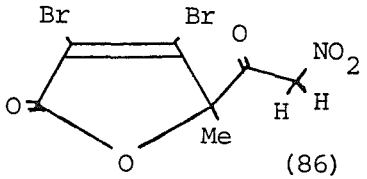


(104)

^{13}C n.m.r.	2-Me		16.8
	4-Me		24.5
	6-Me		28.8
	1		199.4
	2	———	132.8
	3		142.5
	4		136.3
	5		129.9
	6		77.9
^{1}H n.m.r.	2-Me	-	2.08
	4-Me	2.43	2.33
	6-Me	1.52	1.44
	OH	3.5	3.27
I.R.	Hydroxyl	3490	3520, 3450
	Carbonyl	1680	1673
	C=C	1610	1618, 1555
U.V.	nm	351	249, 333
	(ε)	4380	4720, 4020
Melting point		109-110°	86-7°

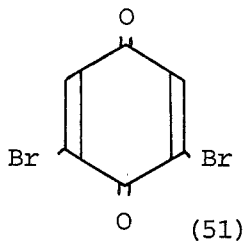
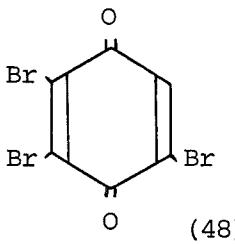
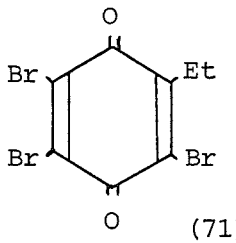
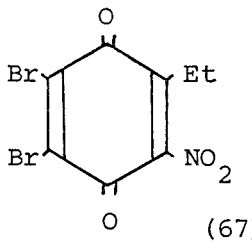
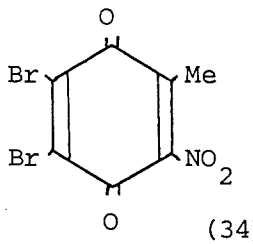


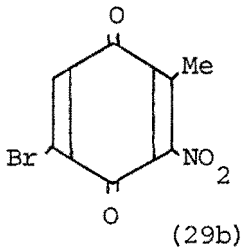
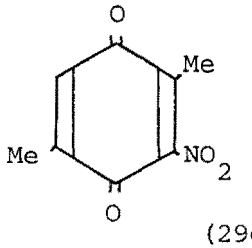
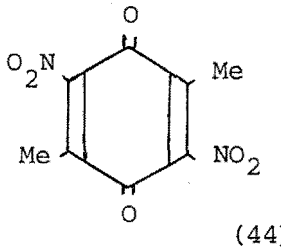
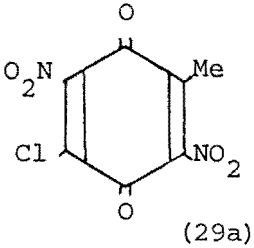
(52)



(86)

^{13}C n.m.r.	Me	-	21.8
	2	162.6	165.3
	3	122.8	118.1
	4	140.4	146.9
	5	156.4	81.3
	6	117.3	192.4
	7	-	92.9
^{1}H n.m.r.	Me	-	1.90
	4H	8.55	-
	7H	-	6.03
I.R.	Carbonyl	1793	1778, 1744
	C=C	1604	1600
	Nitro	1519	1563
U.V.	nm	253, 344	223, 246 340
	(ε)	4600, 16200	12600, 15600 1000
Melting point		121-122.5°	173-4°

		 (51)	 (48)	 (71)	 (67)	 (34)
^{13}C n.m.r.	Me/Et	-	-	11.9, 26.1	13.1, 21.4	
	1	173.4	176.4	171.8	177.0	
	2	139.1	138.4	138.1	141.2	
	3	135.9	138.2	140.1	141.2	———
	4	183.5	171.7	175.6	170.5	
	5	135.9	136.2	134.3	137.3	
	6	139.1	140.2	151.0	-	
^{1}H n.m.r.	Me/Et	-	-	1.13, 2.77	1.19, 2.55	2.21
	5H	7.34	7.50	-	-	-
I.R.	Carbonyl	1694, 1657	1688, 1666	1678, 1664	1679	1676
	C=C	1617	1612	1568	-	-
	Nitro	-	-	-	1552, 1534	1550
U.V.	nm	293, 358	300	304.5	287, 378	284, 368
	(ε)	12000, 850	10700	23900	10400,1110	13200, 1400
Melting point		130-1°	149-150°	117-8°	103-4°	194-5°

		 (29b)	 (29c)	 (44)	 (29a)
^{13}C n.m.r.	2-Me	-	15.2	11.4	-
	5-Me	11.5	11.0	11.4	11.5
	1	171.8	178.9	-	171.8
	2	135.0	145.5	135.9	142.4
	3	139.7	134.8	-	135.4
	4	183.7	186.0	-	183.8
	5	137.3	136.0	135.9	137.5
	6	150.2	162.3	-	-
^{1}H n.m.r	2-Me	-	2.14	2.20	-
	5-Me	2.13	2.08	2.20	2.13
	3H	7.43	6.75	-	7.17
I.R.	Carbonyl	1689, 1667	1673	1678, 1674	1692, 1672
	C=C	1600	1627	1640	1601
	Nitro	1540	1538	1552	1554, 1537
U.V.	nm	277	260	270	271
	(ε)	10700	14600	13100	8500
Melting point		135-7°	51-2°	175°	125-6°

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